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TECHNICAL & SCIENTIFIC PAPERS


Corridors for Shared Prosperity
International Road Federation
TS 1.1 INNOVATION IN DESIGN & CONSTRUCTION

- Segmental Bridge Construction Challenges and Resolutions 6
- Benefits of Virtual Design & Construction in the Nordics 16
- Effect of Strain Rate on the Interface Shear Strength Properties of Interlocked EPS-Block Geofoam 24
- Roads for Water 32

TS 2.1 INNOVATIONS IN TUNNEL DESIGN & CONSTRUCTION

- Karayolu Ulaşım Modunda Tünelcilliğin Yeri, Gelişimi Ve Hedefleri, Türkiye Jeolojik Koşullarının Tünellerin Proje Ve Yapıma Çalışmalarına Olan Etkileri 42
- Türkiye Karayolları Tunellerinin Tarihcesi ve Tunel Güvenlik Kriterleri 50
- Zayıf Kaya Koşullarında, Geniş Açıklı Tünel Yapımı, Kuzey Marmara Otoyolu Çamlık Tüneli Örneği 59

TS 1.3 INNOVATIONS IN ROAD & BRIDGE PLANNING, DESIGN & CONSTRUCTION

- Edirne İl Merkezinde Yer Alan Tarihi Köprülerin Strüktür Sistemlerinin İncelenmesi Ve Tarihi Yapı Tectnolojisini Belirlenmes 69
- Kuzey Marmara Otoyolu Kapsamında Tasarlanan Sanat Yapıları Ve Tüneller 78
- Nissibi Eğik Askılı Köprüsünün Yapım Aşamaları 86
- EAO Cürufunun Karayolu Üstyapısında Kullanımının Araştırılması; Türkiye Örneği 95

TS 2.1 TRANSPORTATION PLANNING & ECONOMICS

- Are Services Provided to Road Users Lost in Translation? 104
- Model Highway Initiative in Black Sea and Central Asia: Towards the Development of Euro-Asian Transport Links and the Facilitation of International Transport and Trade 136
- Transport Corridor Development in Developing Markets: Operational Techniques to Increase Economic Rates of Return for Infrastructure Investments in Transportation Corridor Projects 145
- Innovations In Financing & PPPs of Road Projects 112
- Transport Cooperation Across Borders: Towards Common Transport Policy in the Western Balkans
### TS 2.2 TRANSPORT PLANNING, SYSTEMS & OPERATIONS

- Simulation Modeling of Traffic Impact Analysis with GIS Integration
- Logistics Led Economic Development: Success Factors for Infrastructure Investments

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation Modeling of Traffic Impact Analysis with GIS Integration</td>
<td>153</td>
</tr>
<tr>
<td>Logistics Led Economic Development: Success Factors for Infrastructure Investments</td>
<td></td>
</tr>
</tbody>
</table>

### TS 3.1 INFRASTRUCTURE MAINTENANCE POLICIES & PROGRAMS

- Modeling of the Motorway Network Performance Prediction with Fuzzy Logic and Statistical Analysis Methods
- Maintenance Prioritization of Asphalt Pavements Using Treatment-Based Methods (Case Study: Main Roads of Ilam Province, Iran)
- Local Asset Management Guidelines
- Development of Pavement Serviceability Models for Urban Roads: The Colombian Case
- A Preliminary Study on Cavity Inspection in Pavement Foundation Using Ground Penetrating Radar

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modeling of the Motorway Network Performance Prediction with Fuzzy Logic and Statistical Analysis Methods</td>
<td>162</td>
</tr>
<tr>
<td>Maintenance Prioritization of Asphalt Pavements Using Treatment-Based Methods (Case Study: Main Roads of Ilam Province, Iran)</td>
<td>182</td>
</tr>
<tr>
<td>Local Asset Management Guidelines</td>
<td>190</td>
</tr>
<tr>
<td>Development of Pavement Serviceability Models for Urban Roads: The Colombian Case</td>
<td>200</td>
</tr>
<tr>
<td>A Preliminary Study on Cavity Inspection in Pavement Foundation Using Ground Penetrating Radar</td>
<td>208</td>
</tr>
</tbody>
</table>

### TS 3.2 ASSESSING INFRASTRUCTURE PERFORMANCE

- Management of Low-Volume, Private Roads
- Using a Holistic Approach to Infrastructure Maintenance
- Keeping Europe Moving
- Establishing Optimal Long Term Funding Allocation Based on Network Needs & Availability of Funds
- Asset Management and Performance Management Working Together

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management of Low-Volume, Private Roads</td>
<td>215</td>
</tr>
<tr>
<td>Using a Holistic Approach to Infrastructure Maintenance</td>
<td>221</td>
</tr>
<tr>
<td>Keeping Europe Moving</td>
<td>229</td>
</tr>
<tr>
<td>Establishing Optimal Long Term Funding Allocation Based on Network Needs &amp; Availability of Funds</td>
<td>241</td>
</tr>
<tr>
<td>Asset Management and Performance Management Working Together</td>
<td>255</td>
</tr>
</tbody>
</table>

### TS 4.1 ADVANCED INTELLIGENT TRANSPORT SYSTEMS

- Congestion Charging As a Tool for Improved Urban Mobility
- Industry Readiness Assessment for Day-1 C-ITS Applications
- Intelligent Streetlight Management for Interchanges and Parking Areas in Extra-Urban Environment
- No More Traffic Jams: Tradable Reservations

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congestion Charging As a Tool for Improved Urban Mobility</td>
<td>263</td>
</tr>
<tr>
<td>Industry Readiness Assessment for Day-1 C-ITS Applications</td>
<td>298</td>
</tr>
<tr>
<td>Intelligent Streetlight Management for Interchanges and Parking Areas in Extra-Urban Environment</td>
<td>305</td>
</tr>
<tr>
<td>No More Traffic Jams: Tradable Reservations</td>
<td>311</td>
</tr>
</tbody>
</table>

### TS 4.2 TRAFFIC MANAGEMENT

- Incident Detection Algorithms: A Literature Review
- Road Congestion, Safety and the Planning of Road Network in the Center of Ho Chi Minh City in Vietnam
- Cost Benefit Analysis of Conversion of a Mixed Flow Lane to a BRT Lane - Case Study of Kabul City

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incident Detection Algorithms: A Literature Review</td>
<td>319</td>
</tr>
<tr>
<td>Road Congestion, Safety and the Planning of Road Network in the Center of Ho Chi Minh City in Vietnam</td>
<td>336</td>
</tr>
<tr>
<td>Cost Benefit Analysis of Conversion of a Mixed Flow Lane to a BRT Lane - Case Study of Kabul City</td>
<td></td>
</tr>
</tbody>
</table>
TS 4.3 MANAGING URBAN MOBILITY

- Planning & Setting Up Quality Public Transport Services in the Developing City of Indore, India 345
- New Designs for Signalized Intersections to Enhance Left Turn Treatment 354
- Overcoming Urban Mobility Challenges by Changing Individual Travel Behaviours 354
- Mobility Management using Rapid Transit Systems in Jamaica 361
- Transforming the Future of Transport in Developing Cities - Case Study of Kabul City 361

TS 5.1 ROAD SAFETY POLICIES & PROGRAMS

- Effective & Coordinated Road Infrastructure Safety Operations 374
- Safety Studies and Analysis Covering Ece104 Reflective Contourmarkings on HGV 382
- Implementing Effective Automated Traffic Enforcement in Eastern European & Central-Asian Countries 392
- The Safety Impact of Electronic Enforcement In Malaysia 403

TS 5.2 DATA COLLECTION & ANALYSIS

- Evaluating Driver’s Distraction Factors in Motorways. A Naturalistic Study Based on Driver’s and Road Characteristics 410
- Automated Road Safety Analysis Using Computer Vision Techniques 419
- Safety at Highway-Rail Crossings 419

TS 5.3 DESIGNING SAFER ROADSIDES

- New Life Time Performance of Concrete Vehicle Restraint Systems 428
- Assessment of Barrier Transitions – the French Example 435
- A MASH Compliant W-Beam Median Guardrail System 439
- Crash Cushions: An Overview of Design, Types and Cost 439
- The Use of Computer Simulation for the Development of Vehicle Restraint Systems 446

TS 5.4 SAFETY TREATMENTS

- New Technologies for Road Safety and Maintenance: Shotblasting 461
- Rural Roads Safety Assessment and Countermeasures Plan 468
- Geographic Information System for Intersection Traffic Conflict Assessment in East Tegal Subdistrict, Indonesia 477
- RAINVISION: The Impact of Road Markings on Driver Behaviour - Wet Night Visibility 487
### TS 5.5 MANAGING SAFETY PERFORMANCE

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establishing a Safety Management System for the Non-Urban Road Network - Models Developed and Future Needs</td>
<td>497</td>
</tr>
<tr>
<td>Selection of Road Safety Measures According to Capacity, Safety and Cost Approach</td>
<td>506</td>
</tr>
<tr>
<td>Estimating the Initial Impact of the Long-Term Work Zone Projects</td>
<td>514</td>
</tr>
</tbody>
</table>

### TS 5.6 TRAFFIC SAFETY CULTURE

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Driver’s Training to Improve Transportation &amp; Reduce Emission</td>
<td>521</td>
</tr>
<tr>
<td>Highway Safety: Driver, Vehicle, and Roadway Data</td>
<td>530</td>
</tr>
<tr>
<td>The Traffic Control Operator in Control: Aware of Internal Processes</td>
<td>538</td>
</tr>
<tr>
<td>Integral Safety: The Importance of a Continuous Safety Management Plan</td>
<td>546</td>
</tr>
</tbody>
</table>

### TS 6.1 DURABLE PAVING MATERIALS

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance Evaluation of Micro Surfacing Method Including Added Amount of Buton Natural Rock Asphalt</td>
<td>551</td>
</tr>
<tr>
<td>Effects of Lime on Resilient Modulus Properties of Clayey Soil</td>
<td>559</td>
</tr>
<tr>
<td>Evaluation of the Field Application of Glass-Fiber Reinforced Asphalt Mixtures and Early-Age Performance Monitoring</td>
<td>568</td>
</tr>
</tbody>
</table>

### TS 6.2 MODIFIED PAVING SYSTEMS

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of Impact Resonance Test for Determination of Optimum Rejuvenator Content for Recycled Asphalt Pavements</td>
<td>576</td>
</tr>
<tr>
<td>A Method for Quantifying the Extent of Crumb Rubber Pre-treatment</td>
<td>584</td>
</tr>
<tr>
<td>An Overview of Foamed Based Warm Mix Asphalt and Recent Developments</td>
<td>592</td>
</tr>
</tbody>
</table>

### TS 6.3 MODIFIED PAVING SYSTEMS

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Road with Wastes Incorporation Processing Plants</td>
<td>601</td>
</tr>
<tr>
<td>CBR Behavior of Waste Slag Produced by Zinc Factory for Highway Embankment</td>
<td>609</td>
</tr>
<tr>
<td>Sulfur Extended Asphalt – Properties with the Change of Time</td>
<td>616</td>
</tr>
</tbody>
</table>
TS 6.4 ADVANCED PAVEMENT TECHNOLOGIES (2)  
- Rijit Üst Yapı Şartnamelerine bir Bakış  
- Asfalt Kaplamalarda Kayma Direnci Değerlendirmeleri  
- Kireçtaşının Taş Mastik Asfalt Tabakasında Agrega Olarak Kullanımının Araştırılması  
- Türkiye’de Üst Yapı Yönetim Sistemi Uygulamaları

TS 7.1 SUSTAINABLE TRANSPORT PRACTICES  
- Yerinde Döküm ve Prefabrik Beton Otokorkuluklar  
- Zemine Çakılı Otokorkulukların Darbe Davranışının Sonlu Elemanlar Analiziyle İncelenmesi  
- Yük Taşımacılığında Yönlendirici Algoritmaların Oluşturulması
KEYWORDS: Bridge, Segmental, Construction, Challenges

ABSTRACT:
This paper is intended to outline major challenges to change from conventional cast in place (CIP) to segmental construction techniques. An overview of segmental bridges challenges recorded whilst the construction and measures taken to overcome these difficulties are presented.

The change from conventional cast in place (CIP) to segmental bridges construction techniques has recently gained significant momentum in Middle Eastern countries through construction of many important bridge projects in UAE and other GCC countries. This is because bridges construction using conventional cast in place construction method (CIP) is facing serious criticisms in terms of longer construction period, adverse impact on the traffic movement and nuisance.

The major advantages associated with using segmental construction methods are emphasized; minimizing hindrance to the traffic and public movement in addition to limited workspaces available at urban areas. Moreover, a precast segmental bridge has been recognized as a versatile technique for constructing nowadays fast track projects. Quality control and sustainability aspects coupled with less environmental impact on surrounding have encouraged municipal and local authorities to use this method for bridge construction.

Best practice derived from field experience would remain one of many effective and successful tools to respond to the construction needs, and therefore, construction stages from precast yard setting to segment launching are reviewed. This is including precast segments casting, quality control procedures, logistics and traffic management scheme in addition to launching gantry activities and segment launching.
1. INTRODUCTION

The Middle East region has experienced rapid development over the last two decades, the number of infrastructures and transportation projects are considerably increased to meet the growing demand. Building new highways and bridges projects, that facilitating access and mobility, are major elements of the economic development of any city or country.

In Gulf Cooperation Countries (GCC) area, the transportation sector is challenged even more to invest in massive transportation projects, such as roads and bridges mostly in urban areas, in preparations to host the World Expo 2020 in Dubai and the FIFA World Cup 2022 in Qatar.

The major factors considered in the selection of bridge construction techniques include, but are not limited to the following; a) construction in congested urban areas with minimal impact to the traveling public and traffic, b) minimum construction period, c) low long-term maintenance cost and, d) high aesthetic visibility. All these requirements necessitate using alternative bridges construction techniques other than conventional Cast-In-Place (CIP) methods. Segmental techniques are found to be the most effective option to accomplish all above-mentioned requirements.

2. MAJOR CHALLENGES AND CONCERNS IN ADOPTING THE SEGMENTAL TECHNIQUE

2.1 DESIGN

The design of segmental bridges is one of the most dynamic fields in the bridge construction industry. The main objectives of this technique are to ensure better quality control, early completion, long-term performance and serviceability. The design codes, specifications and guidelines for segmental bridges are always evolving from best practices derived from constructing new bridges and the fast development in construction technology. Moreover, the employer requirements for design should endorse design features that are consistent with the intended objectives in order to provide bridges with long-term serviceability and performance.

Bridges constructability review should always be initiated, studied and verified during design stage prior issuance of the tender documents. Such review is important to define the major factors and constraints include but are not limited to the following; project allocated budget, site location features and surrounding (roads, terrain, landscaping, water, etc.), availability and cost of local materials, existing soil conditions, in addition to, other major design parameters like; geometry, loading and design life. At early stages, the design input from the employer, operation agency and road safety teams is important to deliver design that is more consistent. Moreover, the project duration should be based on realistic and practical construction period estimate.

The design responsibility needs to be clearly identified between stakeholders, particularly, design interface and constraints including traffic management schemes during construction phase. This is because, design changes during construction phase is significantly costly and harming the project completion and therefore, changes during construction should always be very limited or avoided.
2.2 CONSTRUCTION

Construction phase of segmental bridges comprises several processes starting from site preparations, manufacturing of precast concrete segments, studying logistics to transport the precast segments and finally launching girder and precast segments erection. One of the most important features of segmental bridge construction methods is that segments can be casted in areas away from actual bridge site thereby minimizing hindrance to traffic in urban areas. Also, precast segments cast can progress independently and concurrently as works on the foundations and substructure progress and thereby reducing the overall construction period.

Precast yard location should be selected as nearly as possible to the work site and considerations to be taken for segments transportation route to avoid crossing existing bridges with heavy segments. Proper convoy logistic plan to be prepared and approved by local traffic authority to transport the segment along the trafficked roads, mobile repair workshop with safety cars are principle elements of such convoy.

Precast segments production is controlled by sequence of activities with time schedule and therefore, proper flowchart with scheduled activities remains important to accomplish the planned productivity. This overall precast segments production plan should be compatible with segments’ launching operation plan.

Segments launching operation involve several preparation stages in order to ensure smooth launching, gluing and post-tensioning processes. These steps include but not limited to site preparations, logistic plans for segments transportation and temporary storage area for segments nearby launching location. Safety management plan with risk assessment should be in place with proper record of positive and negative findings from different work stages to progressively improve the work plan. One of the useful practices adopted would be discussing launching operation for each span among all site team in a short workshop to define the detailed work plan and identify launching team responsibilities. In addition, superintendence to conduct 15 minutes brief description to the launching team to summarize day or night shift planned activities and team members’ responsibilities.

Epoxy resin glue applies to match cast faces has significant contribution to the entire structure integrity; (i) ensure proper matching between match cast segments through lubricant action, (ii) seal the joint between the match cast segments and provide perfect watertight mean, (iii) contribute to proper stress and shear forces distribution across glued cross section, and (iv) provide perfect watertight to the cementitious grout during ducts grouting operation (Chen & Duan 2014).

Stability analyses to be conducted during launching operation as the boundary conditions with loadings are continuously changing from the beginning of construction to the end. At all launching gantry positions, the foundation and structure must be always stable and have sufficient safety factor against materials failure, overturning, buckling in addition to external factors particularly the wind speed. Launching girder loading and movement should always be subjected to stability check at different positions and loading conditions. Longer span lengths would result in larger unbalance loads for that reason temporary supports are needed in many cases. Conducting full scale load test of the launching gantry is strongly recommended to confirm theoretical truss deflection calculations.

The techniques and procedures adopted in segmental bridges construction have significant impact on the long-term structure performance. (Shemo et al. 2003) The observed challenges in the segmental techniques are:

1. Suitable land available for precast yard and logistic considerations.
2. Suitable land available to assemble the launching gantry at site.
3. Time required to fabricate the launching gantry and precast segments moulds.
4. Precast segments production rate and availability of storage yard nearby the construction site.
5. Actual time cycle for precast segment production is not matching the planned time cycle, Figure 1.
6. Actual precast segment erection time cycle is not matching the planned time cycle, Figure 2.
7. Proper inspection of construction details, observation and rectification of deficiencies.
8. Supervision team should be well qualified, experienced and thoroughly familiar with project specifications and segmental construction techniques.
9. Selection of qualified experienced contractor familiar with segmental techniques.
10. Development of detailed logistic plan compatible with construction sequences.
11. Corrosion protection system for post tensioning anchors and strands should not to be compromised.
12. Record of hanging bars usage and repetition in line with the manufacturer recommendations.
13. Proper treatment for joints between segments and avoid water leak through the joints.
14. Educate the project team to understand the project.
15. Late start to commence superstructure construction is around 12 to 15 months.

Figure 1. Precast (PC) Segment Production Cycle (Othman 2014)

Figure 2. Precast (PC) Segment Erection / Span Erection Cycle (Othman 2014)
2.3 CONTRACTUAL

In any Contract, the nature of obligations and liability issues should be clearly identified as disputes are costly and time consuming. Below are several contractual aspects that need to be considered;

1. Avoid ambiguous statements in the contract conditions.
2. The employer should clearly define the scope of work and avoid changes at critical junctures unless necessitated for proper project completion.
3. Experienced and qualified project team to manage Engineering, Procurement & Construction (EPC) type of contract.
4. The Sub clause “The contractor shall not subcontract the whole of the works” need to be amended to specify the amount in percentage of the works allowed to be subcontracted depending on the nature and size of the project. This is required for better project execution and control. The amendment can be specified in the particular conditions of the contract.
5. Evaluation of the executed works, the site supervision team needs to improve work inspection procedures in order to avoid disruption and delays to construction activities.
6. The employer needs to consider shortening / simplifying the five steps of claim process (notice of claim, substantiation to the engineer and employer, determination by engineer and possibly final determination by the employer).
7. The authority of the external agencies, utilities agencies, shall be clearly specified.
8. Evaluation method and payment process, in particular for EQA type of contracts, should ensure a streamline and efficient evaluation process agreed between the parties.
9. Employer internal system of approving the payment need to be improved to avoid claims for delayed payment.

2.4 QUALITY

The quality control in Precast (PC) segment fabrication to exceed or at least meet the specifications requirements is considered one of the major quality control challenges. The types of defects and preventive measures implemented to avoid or rectify these defects are clearly demonstrated in Figure 3 below.

![Figure 3. Segment Casting / Quality Control (Othman 2014)](image-url)
It is worth to mention that quality management program implemented to resolve the challenges included in the four elements below:

**Plan:** Quality activities are planned at program initiation.

**Act:** Quality activities are implemented.

**Check:** Quality performance is monitored through Quality Assurance (QA) and Quality Control (QC) activities.

**Excel:** Feedback from audits, reviews and lessons learned; and corrective and preventive action is applied to improve future performance.

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**2.5 HEALTH, SAFETY & ENVIRONMENTAL (HS&E)**

The sheer size of the equipment and complexity of the construction process necessitates implementing clear safety mission and target. The combined efforts of a concerned management, responsible and knowledgeable contractor, accountable supervision staff, conscientious and well trained employees are essential requirement to meet HS&E objective. The major challenges faced were creating the safety culture and development of strong communication protocols. The following measures were implemented to overcome the safety challenges and to meet the target (zero incident/accident project):

1. Ensuring sufficient HS&E oversight staff.
2. Education and training.
3. Precaution activities.
4. Safe work practices.
5. Safety protocols.
6. Executive management commitment towards safety.
7. Site risk assessment.
8. Fulfilling the HS&E legal requirements.
10. Safety meetings.
11. Testing and certification of plants and equipment.
12. Statistical reports.
3. SEGMENTAL BRIDGES EXECUTED IN UAE

Figure 5. Dubai Metro (Roads & Transport Authority, Dubai, UAE) (Burke 2014)

- $184M project
- Abu Dhabi Tourism Investment & Development Company
- Parsons Lead Designer
- 4,600 ft. dual segmental bridges
- 635 ft. CIP main span
- 180 ft. incrementally launched approach spans
- CIP concrete V-Piers
- 5 lanes each direction

Figure 6. Saadiyat Bridge in Abu Dhabi (Burke 2014)
- 1.3 KM crossing
- Awarded as Design-Build
- Parsons Role
  - Design of off-bridge civil works and all utilities
  - Construction supervision of all works
  - Contract administration
- 35.8 m wide single cell precast segmental box girders
- Cable stayed main span
- Large diameter shaft foundations

Figure 7. Hodariyat Bridge in Abu Dhabi (Burke 2014)

Figure 8. Palm Jebel Ali Development - PC Erection / Launching Girder (Nakheel, Dubai, UAE) (Othman 2014)
4. CONCLUSIONS

Precast segment technique is proven to be the excellent way to facilitate early completion of superstructure of the bridges, better quality control (factory condition), long term serviceability, easier in construction on live traffic / obstacles etc. Reduced construction period with limited traffic management scheme to construct bridge piers foundation and substructure only while superstructure construction can be conducted with limited traffic management scheme during the night shift when volumes of traffic is considerably low. Decision to use segmental technique is a shared responsibility between the employer and the consultant.
The major challenges faced during construction are found to be avoidable or could be mitigated through establishing proper procedures and guidelines as follows:

1. The selection of qualified, experienced contractor and consultant supervision team. This will have a crucial impact on long term serviceability / performance of constructed bridges.
2. Improvement of inspection details / procedures pre and post construction found to be one of the important factors to mitigate/minimize the defects.
3. Employer team endorsement of their requirement during design stage and avoiding the change during construction is one of the major challenges need to overcome.
4. Constructability review prior to approving design drawing and details is impacting seriously the construction technique, integrity, safety and stability of the structure.
5. Project technical documents sufficiency need to be seriously considered, in particular in EPC type of contract.
6. The role of QA/QC Manager shall be activated and enforced at early stage of the project and maintained during project execution period.
7. Project document recording system is an essential matter need to improved and properly maintained.

REFERENCES


PAPER TITLE
Benefits of Virtual Design and Construction in Civil Engineering in the Nordics

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H.2 Innovation in Construction

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<table>
<thead>
<tr>
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</tr>
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</table>

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<thead>
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</tr>
</thead>
<tbody>
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</tbody>
</table>

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KEYWORDS:
Virtual Design and Construction (VDC), Civil Integrated Management (CIM), BIM for Infrastructure, 3D Engineered Model, Clash Detection, Building Information Model (BIM)

ABSTRACT:
Infrastructure construction projects are typically using 2D design information throughout the project lifecycle and often the as-built information is not utilized or made available for future usage. New innovations in Virtual Design and Construction (VDC) modeling, that uses 3D aspects allows for better use of the data as well as many other benefits. VDC offers benefits for clients, engineers and contractors. Recently the growth of VDC has been seen in many countries and the Nordic Countries seem to be advancing the cause in road, rail and municipal applications. This paper is derived from practical results from actual projects and a special study conducted by the Norwegian National Road Administration. The purpose of the paper is to present quantitative and qualitative benefits of using VDC modeling from the Nordic Countries and share the benefits from case studies. A common and open data standard is an essential framework and vital for the integration of various types of civil engineering information. The results using VDC modeling show improvement in collaboration, identification of design conflicts or clashes, and ability to use the VDC model for optimizing construction, maintenance and operations processes.
Benefits of Virtual Design and Construction in Civil Engineering in the Nordics

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1 INTRODUCTION

Virtual Design and Construction (VDC) is Civil Integrated Management (CIM). VDC is basically the Building Information Model (BIM) being applied to civil engineering applications, such as, roads, rail, airports and municipal technical networks. New technologies based upon Geographic Information System (GIS) are being used in civil engineering projects and being modeled in a 3D environment. This is a great improvement over 2D drawings. 3D designs also have other benefits that will be addressed in this paper.

The use of VDC is increasing in many countries and public clients are a large beneficiary of this recent technology. VDC modeling can be initiated as early in the conceptual planning phases as possible, but more importantly, it can be used throughout the life cycle of a project. This means the information/data can be used for planning, design engineering, construction, project delivery, and for future maintenance or asset management. This can benefit the client throughout the life cycle by allowing better collaboration, designs, quality and savings during the construction phase.

Once the VDC model is built, contractors can use the existing model for their Automated Machine Guidance (AMG), stake-out data, create as-built drawings, scheduling (4D) and costs (5D). This results in savings because the data may be used for automated processes, better information accessibility and for future maintenance practices. There are other potential benefits that have not been fully adapted such as using the model for augmented reality.

The paper will provide examples from real life projects that have used the VDC model and provide some quantitative and qualitative findings. The paper is intended to summarize results from projects, discuss VDC benefits and discuss findings from a study in Norway. It is intended to demonstrate the potential of VDC and hopefully create interest for various stakeholders.

2 METHODOLOGY & OBJECTIVE

The methodology of this paper is from summaries of real life projects, personal experiences from the authors and results from the Norwegian Public Road Administration (NPRA).

The objective of the paper is to disseminate findings from VDC projects and discuss the benefits and challenges of VDC.

3 BACKGROUND

Virtual Design and Construction (VDC) is an emerging technology that has its roots from the Building Information Model (BIM). Over the past years VDC is being applied to what is commonly called the horizontal construction or infrastructure markets. VDC also provides tools for better communication and coordination, resulting in more productive infrastructure projects. VDC allows digital prototypes to be built,
communicate design intents to key stakeholders, avoid conflicts early in the design process and produce better design quality.

Several countries are already using VDC in one form or another and some have followed the global movement from traditional 2D practices towards the collaborative phase, with a vision to become more integrated. Figure 1 shows an example of the progression from traditional practices towards this new paradigm. This can be seen as an international phenomenon. Many engineers understand the benefit of collaborating and potential to improve the design engineering process. Creating the VDC model in a 3D environment has many benefits and the data can be accessed quicker and through virtual means.

VDC does not end at the design phase and can be used during the project construction, providing the VDC model is built from all its intended components. The intent is to build an integrated model of the proposed project (consisting of terrain, structures, utilities and all assets), which can be used throughout the lifecycle. Often, clients are only using 3D for visualization and marketing the project and miss the benefits of completing the VDC model. Once the complete model is built, the Contractors can begin construction by using the VDC model to prepare the earthworks via Automated Machine Guidance (AMG) from the LandXML output. Via LandXML the different elements can be divided for the AMG, and the equipment and technologies are available today. Even the quality of the construction is better as the accuracy is much better from digital data versus human judgement.

The other possibilities during the construction phase is the ability to use the model for 4D (scheduling) and 5D (costs). If the VDC model is built, the contractor can schedule the processes and have the ability to simulate different phasing to the project for an efficient process. Also, the costs calculations can be added to the scheduling process and easily estimated the payment cycles that are aligned to the actual construction process.

The overall result of using VDC is less cost during the construction phase because of the efficiency gains, productivity improvements and the contractors can rely on good quality designs to drive the contractor’s processes. Figure 2 shows the savings are achieved during the construction phase despite increased costs for early adoption of the VDC model and learning/training from the early development. Subsequently, future projects will be easier to streamline after the learning curve.
4 BENEFITS & CHALLENGES OF VDC

VDC offers different benefits for different parties involved in VDC. The Clients, engineers and contractors are typically the main beneficiaries of VDC. Also, the project delivery method selected for the project has an effect to the benefits realized by the various parties.

4.1 Savings to Clients

The main benefit for clients and owners is the savings potential from VDC. The client benefits from VDC by early capture of design conflicts, better design quality and collaboration, and the use of the VDC data during the construction phase. Design conflicts can be significantly reduced during the early design phases by the use of “clash detection” in a 3D environment. Most design errors can be avoided, which may lead to fewer change orders during the construction phase.

The contractor can use the VDC model for their Automated Machine Guidance (AMG) and use the model for the 4D and 5D. This can reduce construction costs significantly and provide savings to the client and contractor.

4.2 Increased Productivity and Quality

During the pre-construction phases, it is possible to conduct various types of analysis, performance exercises, and add value to the design by simulating different alternatives and options, or so called what-if scenarios. Also, life cycle costing and environmental considerations can be done, which increases the quality of the design.

During the construction phase the result is shorter project durations, efficient processing and the accuracy of cost estimations. As a result productivity is increased and costs are reduced via this efficient means.

4.3 Better Management

Easier visualization with the use of VDC helps customers understand design alternatives. Data can be exploited during the entire project lifecycle to facilitate the management process. VDC supports collaboration in project delivery throughout all project phases and the client is provided with a comprehensive understanding of the project’s nature and needs.

Construction management and project management during construction, operations, and maintenance phases are more efficient when there is collaboration throughout the lifecycle. Since the data is already in the 3D model, management is simpler since the all the information is available.
4.4 Interoperability

There are many data modelling technologies and interoperability development projects completed and it appears that Finland and Norway are some the unique progressive countries leading the way forward. Interoperability requires that data transfer standards are able to interchange between data systems. In Finland, there are data transfer standard for infrastructure projects called Inframodell, which defines how data is transferred between design systems, and from design to construction. The bidders can download the initial data model and clients can send offers using open data formats.

The main issue is that data can be shared interoperably by common data transfer standards and is more advantageous if the client leads the charge and becomes the driver of VDC applications.

4.5 Lifecycle Approach

Often maintenance and operations over the lifecycle has been neglected for many reasons and probably because of the culture and systems already imposed. The VDC model offers better data management during operations and maintenance phases so that the all the information is already available in the VDC model to apply the maintenance strategy and plan processes accordingly. Typically after construction, the handover of data information is not readily available for the maintenance personnel.

This is presently being researched and using the VDC model for asset management is underway in some countries. It is still in the early processes and under development, but it can be seen as added-value feature for further benefits especially for clients.

5 CHALLENGES OF VDC

Not only are there benefits for VDC modeling, but there can be some significant barriers and challenges to the adaptation to VDC. One significant challenge is changing the client organization to change from traditional processes to a VDC model and a 3D approach. Changing the existing processes to a common understanding of VDC modeling is a significant issue to be overcome. Presently, there may not be support for common modelling practices and their instructions are inadequate to implement immediately. There is more resistance among clients and owners, as opposed to the experience among designers and contractors.

5.1 Organizational challenges

Organizational challenges are very common issues and the so called “stove-piped” organizational processes are difficult to overcome. Some common complaints from internal organizations include the approval and agreement procedures for VDC models, the lack of coordinator throughout the entire project, managing the VDC data, legal implications, the lack of information regarding the requirements for VDC as a common process, and procurement methods centered on document-based processes and practices.

5.2 Resistance to Change

Resistance to change is also a challenge as many are used to doing things in the same way as previously and are not comfortable with change. This can be seen as a personal barrier as new technologies are emerging and that new systems and processes need to be changed and potentially threatens comfortable positions and may require new thinking. It is also possible that the management is not committed to change of procedures or desires a slow and deliberate testing nature. Most professional skilled employees are used to traditional processes and might not be aware of the new VDC way of doing infrastructure projects.

5.3 Interoperability, ICT and Training Issues

Interoperability, Information and Communication Technology (ICT) and training issues are other obstacles that need to be overcome. Several issues may include formatting and common rules and standards, common modeling guidelines, interoperability problems between different types of assets, lack of resources and finances to develop into the VDC paradigm, and additional training to become proficient in VDC modeling. There may be a perception that visualization and 3D modeling are difficult to use and are cumbersome.
Another important challenge to overcome is the use of existing tools and design software. Many have been trained in using existing software systems for many years and adding new tools might be perceived as additional expenses and the use of unknown tools.

Training will be required in any new environment, but there are new tools that are relatively easy to use and adapt.

6 RESULTS & CASE STUDIES

The Norwegian Public Road Administration (NPRA) has evaluated the results between projects using the VDC model and those that using traditional practices. The results are very interesting and are shown in Figure 3.

<table>
<thead>
<tr>
<th>Project</th>
<th>Contract sum</th>
<th>CCO %</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV 150 - E93, Ring 3 Ulven-Sinsen</td>
<td>301 mill</td>
<td>18.9%</td>
</tr>
<tr>
<td>RV 150 - E22, Ring 3 Ulven-Sinsen</td>
<td>532 mill</td>
<td>9.8%</td>
</tr>
<tr>
<td>E6 - Nordre, Trandum</td>
<td>263 mill</td>
<td>7.6%</td>
</tr>
<tr>
<td>Fr. 456 Vågsbygdalen</td>
<td>43.7 mill</td>
<td>4.2%</td>
</tr>
<tr>
<td>E6 Skaberud - Kalomoen</td>
<td>470 mill</td>
<td>18.1%</td>
</tr>
<tr>
<td>Joint Project E6- Dovrebanen</td>
<td>1.8 mld</td>
<td>8.3%</td>
</tr>
</tbody>
</table>

Source: Norwegian Public Road Administration

Figure 3 shows the results of six projects, with four using the VDC/BIM (Building Information Model) and two using the traditional processes. The results indicate that the percent of change orders (CCO) decreased from an average of 18.5% to 7.5%, when using the VDC/BIM model. This is a significant reduction in change orders that can be achieved by using the VDC/BIM model. It is important to notice that Norway for some unknown reason has great deal of change orders using traditional practices versus those form other countries. However, the most important finding is that there are 2.5 times fewer change orders when using the VDC/BIM model.

6.1 Case Study Norway RV 150 Ring Road 3, Ulven–Sinsen

The case study of Norway’s RV 150 Ring Road 3, from Ulven to Sinsen is a good example of significant benefits to the Norwegian Public Road Administration (NPRA). On this test case study the project was split into two parts, with the first part using the traditional practices and the second part used the VDC/BIM model. Some of the significant findings from this project are as follows:

- Part 1 ➔ About 250 out of 600 changes were caused by design conflicts
- Average costs per design conflict/changes were calculated at $9600
- Part 2 ➔ There were essentially no design/conflicts on this section
- Potential savings of $2.4 million

Figure 4 shows a picture of the Norway RV 150 Ring Road.
6.2 Case Study Norway 31774 Gjønnes Rail Station

The case study of Norway’s 31774 Gjønnes Rail Station is an example of a rail station that was built in Gjønnes, Norway. Figure 5 shows a picture of the Norway 31774 Gjønnes Rail Station. On this test case study the project shows significant findings from this project are as follows:

- Total of 350 design conflicts were found
- Approximately 50% of conflicts would not have been detected without VDC
- NPRA estimated a potential savings of $1.7 million

6.3 Case Study Finland Ring-I Mestari Tunnel

The case study of Finland’s Ring-I Mestari tunnel, is located in Espoo, Finland is a good example of other benefits using the VDC model. Some of the significant findings from this project are as follows:

- VDC model for simulating traffic guidance and safety
- Sequence planning
- Virtual training and testing for fire fighters
- Traffic camera placement
- Daylight/Sunlight protection
- Major time savings in completing project (Delivery 3 months early)
- Overall project 1 year earlier
- 2010 award for the infrastructure construction of the year
6.4 Case Study Finland West Metro Rail Extension

The case study of Finland’s West Metro Rail Extension is located from Helsinki to Espoo, Finland and is an example of a large city infrastructure project that is fully committed to using the VDC model. Figure 6 shows a picture of a station in Finland’s West Metro Rail Extension. This means that the VDC model will be used for the maintenance and operations portion too. Some of the present benefits of using the VDC model for this project are as follows:

- A fully combined data model
- GIS (GML: surroundings)
- CIM (LandXML: subway)
- VDC (IFC: structures, MEP)
- Target in maintenance:
- As-built model
- Maintenance planning and operations in 5D
- Digital service manual and 3D model & mobile augmented reality
- Lifecycle Management (Design, Construction, Maintenance & Operations)

![Figure 6. Finland’s West Metro Rail Extension](image)

7 CONCLUSIONS

The use of VDC modeling in the Nordic countries has resulted in savings, better collaboration, ability to create one model for the entire project, reducing design conflicts, ability to use the model for contractors’ AMG, 4D & 5D, and that the model can be used throughout the lifecycle. VDC has also shown value added benefits like training, simulation, value engineering and various visualization applications.

The use of VDC has challenges to overcome such as changing the internal organizations processes, structure and resistance to change. The new paradigm from 2D to 3D and VDC modeling is seen as a potential tool for future infrastructure projects and is having similar development issues as with the Building Information Model (BIM) in the buildings technology area.
PAPER TITLE: Effect of displacement rate on the interface shear strength properties of interlocked EPS-block geofoam

TRACK: 0215

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KEYWORDS:
Geofoam block, lightweight fill, interface shear strength, interlocked geofoam, displacement rate.

ABSTRACT:
Lightweight expanded polystyrene (EPS) block geofoam (geofoam block) is commonly used throughout the world to construct highway embankments over soft soil for which settlement is a major concern. Due to their lightweight nature, geofoam block roadway embankment systems not only significantly reduce the amount of consolidation settlement but also reduce the duration and cost of the construction. The geofoam block to geofoam block interface shear resistance is an important design parameter in terms of internal stability analysis under horizontal driving forces of highway embankments. In order to enhance the geofoam block to geofoam block interface friction characteristics and thus increase resistance to shearing forces, an interlocked geofoam block was designed in which a solid geofoam block was trimmed in such a way that a total of four ledges along the top and four notches along the bottom surface were formed. This way, the continuous horizontal shearing plane in-between solid geofoam blocks was interrupted. Direct shear testing technique was utilized to quantify the characteristics of the interface friction properties of the interlocked geofoam block surfaces. Two different types of geofoam blocks (EPS19 and EPS29) were used to investigate the effect of density. Three different displacement rates (1-, 2-, and 4 mm/min) were applied during the shear phase to investigate the effect of displacement rate on shear stress-strain characteristics of interlocked geofoam blocks. In addition, interface shear strength properties of solid geofoam block to geofoam block interface properties were determined not only for comparison purposes with the reported literature values but also to demonstrate the improvement provided by utilizing interlocked surfaces. The interface shear strength characteristics, regardless of geofoam block density, were not affected by the different displacement rates used in this study. The use of an interlocked surface changed the interface shear behavior of the solid geofoam blocks from purely frictional to frictional-adhesional regardless of the density and displacement rate.
Effect of displacement rate on the interface shear strength properties of interlocked EPS-block geofoam

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1 INTRODUCTION

Constructing highway embankments over soft soil sites where the settlement is a major design consideration, civil engineers generally have two design options: The first option is to implement a feasible conventional soil improvement technique so that the construction of the embankment takes place over improved subsurface using conventional earth fill. Instead of improving the subsurface soil conditions, the second option comprises of utilizing lightweight fill material. Constructing the highway using lightweight fill material significantly reduces the embankment load which is the primary cause for settlement.

Lightweight expanded polystyrene (EPS) block geofoam (geofoam block) is made of raw styrene that undergoes an expansion process by adding pentane and steam (Koerner, 2012). Geofoam blocks are only 1 to 3% as heavy as the conventional earth fill materials used in the construction of highway embankments (Koerner, 2012). This unique lightweight fill material significantly reduces the external embankment loading. The physical property requirements of geofoam have been standardized by ASTM D6817, and EUMEPS (2011).

Geofoam block is commonly used for highway embankment construction throughout the world to remediate settlement for embankments built on soft soil sites (Beinbrech and Hillmann, 1997; Perrier, 1997; Aabøe, 2011; Herle, 2011; Papacharalampous and Sotiropoulos, 2011, Youwai et al., 2011). Construction of highway embankments and bridge approach ramps using geofoam blocks is a well established and mature technology. The design guidelines for geofoam embankments have been published by Norwegian Road Research Laboratory supported by Norwegian Public Roads Administration (NRLL, 1992), and National Cooperative Highway Research Program (NCHRP) supported by Transportation Research Board (Stark et al., 2004).

Internal stability analysis of geofoam block embankments consists of three steps: transition due to water (hydrostatic sliding), transition due to wind, and seismic stability analysis (Stark et al., 2004). Quantification of the available shear resistance in between geofoam block layers (geofoam block to geofoam block) is a major design step for these three analyses. Consequently, geofoam block to geofoam block interface shear resistance needs to be evaluated. Geofoam block to geofoam block interface shear strength properties have been well established by various researchers (Sheeley, 2000; Sheeley and Negussey, 2000; Atmatzidis et al., 2001; Negussey et al., 2001; Barrett, 2008). In addition, both NCHRP (Stark et al., 2004) and Norwegian guidelines (NRLL, 1992) recommends design values for interface shear strength properties of geofoam blocks.

Geofoam block to geofoam block interface shear resistance may be insufficient to resist the horizontal driving forces during significant seismic activity. In order to enhance the geofoam block to
geofoam block interface friction characteristics and enhance resistance to induced shearing forces, various countermeasures such as mechanical connectors along the horizontal interfaces of geofoam blocks (AFM Corporation, 2011), shear key concept (Bartlett and Lawton, 2008), polyurethane adhesives (Barrett and Valsangkar, 2009; Amini, 2014), and “C” and “H” shaped geofoam blocks (Kurose and Tanaka, 1996) have been proposed.

As an alternative to above listed available techniques of enhancing the interface shear strength properties of geofoam blocks, an interlocked geofoam block was designed in which a solid geofoam block was trimmed in such a way that a total of four ledges along the top and four notches along the bottom surface were formed. Direct shear testing method has been selected to quantify the interlock configuration on interface shear strength properties. Selection of a displacement rate is an important initial parameter to run a direct shear test. Therefore three different displacement rates (1-, 2-, and 4 mm/min) were applied during the shear phase to investigate the effect of displacement rate on shear stress-strain characteristics of interlocked geofoam blocks.

2 MATERIALS AND METHODS

Two different densities of geofoam blocks (EPS19, and EPS29 based on ASTM D6817) were used in order to investigate the effect of material hardness on the interface friction properties. The compressive strength properties were measured using a series of four samples according to ASTM D1621. The average density of EPS19 was 18.5 kg/m$^3$ and average compressive strength at 1% strain was 40.2 kPa, and the average density of EPS29 was 29.9 kg/m$^3$ and average compressive strength at 1% strain was 95.2 kPa.

Test specimens for the interface direct shear testing program were prepared in two groups. The first group of the specimens was consisted of two solid geofoam blocks which were set atop each other (Figure 1a) to quantify the geofoam block to geofoam block interface friction properties. Specimens were prepared using a hot wire cutter. The top specimen was prepared to the dimensions of 2.5 cm high, 10 cm wide and 10 cm long and the bottom specimen was trimmed to the dimensions of 2.5 cm high, 10 cm wide and 15 cm long (Figure 1a). Therefore a 10 cm x 10 cm interface shear surface has been created. The second group of specimens was consisted of interlocked geofoam block configuration. The interlock configuration was consisted of four ledges and notches belong to lower and upper specimen, respectively (Figure 1b). Both ledges and notches are 0.5 cm wide, 0.5 cm high and 10 cm long (Figure 1b). This way, the continuous horizontal shearing plane in-between solid geofoam blocks was interrupted. This group of specimens was also set atop each other in direct shear device (Figure 1b).

Figure 1. Interface shear test specimens (a) Geofoam block to geofoam block interface test specimen (b) interlocked geofoam block configuration consisted of four ledges and four notches

There is no unique standard test method available to quantify the interface friction properties of geofoam block to geofoam block interfaces. However, following Özer and Akay (2014), ASTM D5321 which has been prepared for determining the shear strength of soil-geosynthetic and geosynthetic-geosynthetic interfaces by direct shear test according to ASTM D3080 was used.
The fully automated direct shear test system of Geocomp Corporation (2011) was utilized to quantify both geofoam block to geofoam block and interlocked geofoam block configuration interface shear strength properties (Figure 2). The interface shear strength tests were conducted under four different constant vertical stresses (10, 20, 30 and 40 kPa) applied to the specimen via 10 cm x 10 cm loading cap (Figure 2b). Three different displacement rates (1-, 2-, and 4 mm/min) were applied and maintained constant during the shear phase of the tests via horizontal stepper motor to study the effect of displacement rate on the interface strength properties. While the lower specimen moved horizontally towards the horizontal load cell which was fixed to the direct shear test frame, the upper specimen held in place by horizontal loading cap attached to the horizontal load cell (Figure 2). Therefore, horizontal interface shear forces were captured by horizontal load cell. Both the vertical and horizontal displacements were measured by vertical and horizontal LVDTs during the test.

![Figure 2. Direct shear test frame](image)

3 RESULTS AND DISCUSSIONS

Geofoam block to geofoam block interface shear stress – strain curves for both EPS19 and EPS29 have been shown in Figures 3a and 3c, respectively, for all three different strain rates used. All of the geofoam blocks to geofoam block interface shear tests were terminated when 20% of horizontal strain was reached. ASTM D3080 defines the failure as the peak shear strength value obtained during the test or the shear stress at 10% strain, whichever was obtained first during the geofoam block to geofoam block interface shear tests. Based on this criterion, failure envelopes (peak and residual) for both EPS19 and EPS29 have been shown in Figures 3b and 3d, respectively. In addition, both peak and residual interface shear strength properties for the tests conducted under three different strain rates were also summarized in Figure 3.

The interface shear stresses increased rapidly under all constant vertical pressures for EPS19 when horizontal strain is between 1 and 5% (Figure 3a). Peak and residual interface shear strength values were clearly identified for all the tests except for 40 kPa of vertical stress with 1-mm/min displacement rate. Therefore, by following failure definition of ASTM D3080, the shear stress value at 10% strain was considered as the peak horizontal interface shear stress for this test, and residual condition was not developed. Regardless of the displacement rate, the interface shear stresses also increased rapidly under all constant vertical pressures for EPS29 and both the residual and the peak shear stresses were clearly indentified for all of the interface shear tests conducted for EPS29 (Figure 3c). The stress-strain curves and the peak and residual interface shear strength values obtained were close to each other for both EPS19 and EPS29 regardless of the displacement rates used. Consequently, stress-strain behaviors were not affected by the different displacement rates used in this study (Figures 3a and 3c).
The Mohr-Coulomb failure envelopes and their peak interface shear strength parameters (adhesion, $c_a$ and interface friction angle, $\delta$) of geofoam block to geofoam block samples were provided for EPS19 and EPS29 in Figure 3b and Figure 3d, respectively. Failure envelopes indicated that the friction mechanism along the geofoam block to geofoam block interface is purely frictional ($\delta > 0$ and $c_a = 0$) regardless of the geofoam block density and the displacement rate used. The peak interface shear stresses obtained from EPS19 specimens were less than that of EPS29 under the same vertical stresses for all displacement rates. The peak interface friction angle varied between 37.2° and 40.5° for EPS19 (Figure 3b) and varied between 39.5° and 44.4° for EPS29 (Figure 3d). The residual interface friction angle varied between 32.2° and 37.6° for EPS19 (Figure 3b), and varied between 29.9° and 32.2° for EPS29 (Figure 3d). Based on both stress-strain characteristics and resulted failure envelopes, the displacement rate used in this study did not significantly affect the test results. Regardless of the displacement rate used, the peak interface friction angles obtained for EPS19 were less than that of EPS29.

Geofoam block to geofoam block interface shear strength properties has been researched by various researchers using the wire cut samples like the ones prepared for this study. The reported interface shear stress values for EPS19 varied between 40° and 48.5° for peak and 34.2° and 35° for residual interface friction angles (Sheeley, 2000; Sheeley and Negussey, 2000; Atmatzidis et al., 2001; Barrett and Valsangkar, 2009). The reported interface shear stress values for EPS29 varied between 40.4° and 46.7° for peak and 33° and 40.7° for residual interface friction angles (Sheeley, 2000; Sheeley and Negussey, 2000; Atmatzidis et al., 2001; Barrett and Valsangkar, 2009). Therefore, both interface friction angle and interface friction factors measured in this study were consistent with the reported values in the literature.

Progress of interface shear test on the interlocked geofoam block surface is given in Figure 4. Test photos were taken at 30 s intervals which correspond to 1% strain increment for a test conducted using 2-
mm/min displacement rate. Ledges of the lower geofoam sample resisted horizontal interface forces and eventually started to yield when horizontal strain is about 4% to 5% (Figure 4). Yielding of first ledge, located left hand side of the Plexiglas horizontal loading cap, was visible at these strain levels (Figure 4). After the initial yielding, this ledge started to lose its contact when reaching 9% of horizontal strain (Figure 4). At this strain level the second ledge, located left side of the first one, started to yield. The first and second ledges were failed and the third ledge started to yield at 13% strain (Figure 4). The first three ledges were failed and fourth one started to yield at 14% strain and all of the ledges were completely failed at 15% strain. Based on these observations, interface shear tests for interlocked samples were terminated at 5% horizontal strain at which the first yielding was observed.

Interface shear stress – strain curves for both EPS19 and EPS29 has been shown in Figures 5a and 5c, respectively, for all three different strain rates used. In addition, failure envelopes for both EPS19 and EPS29 for interlock configuration can be found in Figures 5b and 5d, respectively. Except for interface tests conducted under 10 and 20 kPa vertical stresses of EPS29 specimens, no clear peak has been identified for the rest of the tests (Figures 5a and 5c).

Figure 4. Progress of interface shear test on interlocked geofoam block surfaces under 10 kPa of vertical stress with 2-mm/min displacement rate
Figure 5. Interface test results for interlocked geofoam block interface (a) Shear stress – strain curves for EPS19 (b) Failure envelopes for EPS 19 (c) Shear stress – strain curves for EPS29 (d) Failure envelopes for 30 kg/m³ density blocks

Interface shear strength at 5% horizontal strain were taken as peak shear stress and peak failure envelopes provided in Figures 5b and 5d for EPS19 and EPS 29, respectively. Contrary to purely frictional mechanism for geofoam block to geofoam block samples, the shearing mechanism of interlocked geofoam blocks was frictional adhesional ($\delta > 0$ and $c_a > 0$) since the failure envelopes of interlocked samples defined by not only interface friction angles but also has adhesion components (Figures 5b and 5d). The peak interface friction angle varied between 5.1° and 9.6° for EPS19 (Figure 5b) and varied between 17.1° and 24.1° for EPS29 (Figure 5d). The interface adhesion varied between 21.7 kPa and 25.2 kPa for EPS19 (Figure 5b), and varied between 37.6 kPa and 43.6 kPa for EPS29 (Figure 5d). The shear stress – strain behaviors (Figures 5a and 5b), and failure envelopes (Figures 5b and 5d) were close to each other for both EPS19 and EPS29 for the tests conducted with different displacement rates. Consequently, like geofoam block to geofoam block interface, stress-strain behaviors of interlocked geofoam blocks were not considerably affected by the different displacement rates used in this study (Figures 3a and 3c). EPS29 has higher peak adhesion and peak interface friction angle values than that of EPS19.

5 CONCLUSIONS

The proposed interlocked configuration significantly enhanced the traditional geofoam block to geofoam block interface friction characteristics. Utilizing interlocked blocks changed the interface shear strength characteristics of the blocks being from purely frictional to frictional adhesional. This study has shown that regardless of the geofoam blocks hardness, the effect of the strain rate on the interface shear strength characteristics of both geofoam to geofoam and interlocked geofoam surfaces is not significant under the rates used. EPS29 has higher interface shear strength properties than that of EPS19 for both solid and interlocked surfaces.
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REFERENCES


PAPER TITLE: Water harvesting from roads: climate resilience in Tigray, Ethiopia

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KEYWORDS: Roads, water harvesting, resilience, Ethiopia

ABSTRACT:
The development of roads nowadays often has negative impacts. Roads cause floods and water logging along the way, whereas the more concentrated run-off from drains and culverts cause erosion and sedimentation. These negative impacts are often related with the practice in road engineering to evacuate water away from the roads as soon as possible rather than making use of the water for beneficial purposes. This negative character however can be turned around and roads can be used as instruments for water harvesting. This can generate substantial positive impact especially as water is getting scarcer. With the investment in roads in many countries exceeding that of any other programmes, there is a large opportunity to improve the productive environment and increase the climate resilience of the population in the vicinity of the road.

In Tigray, the northernmost region of Ethiopia, steep slopes have been cultivated for many centuries and are subject to serious soil erosion. This problem can be exacerbated by improperly planned road development, posing a serious threat to the livelihoods of people who survive by subsistence agriculture on areas adjacent to the road. This article presents an assessment of the effects of the concentrated run-off from roads on the surrounding environment. It also explores the status and opportunities for water harvesting from roads in the Frewaign-Hawzien-Abreha Weatsbeha-Wukro route in Tigray, Northern Ethiopia.
1. Introduction

With 7-10 Billion USD invested annually in roads in Sub Saharan Africa alone and 70,000 kilometer of new road constructed a year, roads have a major impact on water management and on the environment immediately surrounding them (Kubbinga 2010).

In Sahel roads sometimes inadvertently cause sand dune movement – they open up deserts and create wind tunnels when positioned in the dominant wind direction. In the Mekong Delta in Vietnam and Cambodia roads affect flooding patterns but also fish movement. Roads serve as dikes in coastal zones as in Bangladesh, yet there is a sometimes compromised balance between transport convenience and flood protection safety standards.

In pastoral lowlands in South Sudan roads determine flooding patterns and hence moisture availability and with this timing to regenerate the grazing area through bushfires. Then, the proliferation of feeder roads in recent years has connected many previously remote areas, but the dust they create is a health issue and affects crop productivity too. In summary roads not only have a major impact on the transport of people, goods and services, but they equally have a major impact on the environment immediately surrounding them – the movement of water, sediment, wild-life and others. Roads have a particular important impact on water run-off, because the facto roads either serve as water embankment or a drain. Roads are one of the major elements in a landscape and their development and maintenance should preferably be managed that way.

The development of roads nowadays often has negative impacts. Roads cause floods and water logging along the way, whereas the more concentrated run-off from drains and culverts cause erosion and sedimentation. These negative impacts are often related with the practice in road engineering to evacuate water away from the roads as soon as possible rather than making use of the water for beneficial purposes.

This negative character however can be turned around and roads can be used as instruments for water harvesting. This can generate substantial positive impact especially as water is getting scarcer. With the investment in roads in many countries exceeding that of any other programmes, there is a large opportunity to improve the productive environment and increase the climate resilience of the population in the vicinity of the road.

In addition, road water harvesting can also contribute to road longevity. In many cases In Ethiopia for instance problematic drainage is the most common factor in construction delays and water is the cause of 35% of the road damage. Yet proper drainage on unpaved feeder roads is not only the essence of preventing damage but also creates the opportunities to divert water to adjacent farm land or storage reservoirs. Another example is that culverts and river crossings often trigger the development of gullies because they concentrate run-off. Given time these gullies will undermine the road itself too. Here again the foe can be turned into a friend by utilizing the water that exits from the culverts.

Road development changes the surface and sub-surface hydrology; roads massively change run-off patterns and can collect water from their own surfaces and this is a phenomena that should be put into beneficial use (García-Landarte et al. 2014). This paper discusses the program of road water harvesting in Tigray, Ethiopia where the negative is being changed into a positive. The paper discusses first the situation as it existed with much distributed damage (section 2) and then presents some highlights of the road water harvesting campaign that was started in 2014. The paper concludes with a plea that roads can contribute importantly to climate resilience not by making the road itself climate proof but by contributing to better resource management in the surrounding landscape whilst at the same time safeguarding the integrity and sustainability of the roads.

2. The negative impact from road development

This section discusses research on road impact undertaken along the route Freweign-Hawzien-Abreha Weatsbeha-Wukro in Tigray, Northern Ethiopia in 2013-2015. This road section of 64 kilometer length crosses three woredas (districts): Saesie Tsaeda Emba (woreda center is Freweign town), Hawzien woreda (woreda center is Freweign town), and (c) Klite Awlaelo woreda (woreda center is Wukro town) (Figure 1). The surveyed
routes include both feeder roads and asphalt: Freweign-Megab route is asphalt, and Megab-Abreha Weatsbeha-Wukro route is all weather gravel road.

![Location map of the Freweign-Hawzien-Abreha Weatsbeha route, Tigray, Northern Ethiopia.](image)

**Figure 1. Location map of the Freweign-Hawzien-Abreha Weatsbeha route, Tigray, Northern Ethiopia.**

According to the Ethiopian CSA (2007), an estimated total population of 236,486 (51.7% female, 48.3% male) live in the three aforementioned woredas. About 76.4% of the total population live in rural areas. Communities in the study area have been food insecure for a number of reasons including land degradation, water insecurity due to short rainy season coupled with high rainfall variability between seasons, small land size that rarely exceeds 0.5 ha per family and absence of irrigation practices.

The landscape of the study area presents a wide range of landforms. The slope gradients range from flat plains to over 40%. The geohydrology of Tigray region in general and the study route in particular is highly variable. Silty sand soils are the most dominant type along the route. Results of inverse auger hole test revealed that the permeability of these soils ranges from $2.5 \times 10^{-2}$ cm/sec to $3.4 \times 10^{-3}$ cm/sec. Most of the unconsolidated sediments along the route are categorized as good aquifers for shallow groundwater development. This has led to extensive shallow groundwater development in the plains of the study area. Groundwater is the main source of water for domestic use in the area. Moreover, shallow groundwater is increasingly used for small-scale irrigation in the area (Woldearegay and van Steenbergen, 2014). Out of the total 1800 hectares of potential irrigable land, 550 ha was irrigated in the year 2013 using shallow groundwater mainly. In the year 2014, the irrigated land has increased to 610 ha using shallow groundwater systems. The maximum land size that a single farmer was able to irrigate in the year 2013 (using shallow groundwater and other sources) in the area was 30% of the cultivable land. The limiting factor for irrigation expansion in the area is shortage of water.
As mentioned, if water from roads is not handled properly, the result is erosion, flooding, and siltation/sedimentation due to the disturbance of natural drainage systems. Such was the case along the Freweign-Hawzien-AbrehaWeatsbeha-Wukro road section as well. A detailed assessment was done of: locations of culverts, Irish bridges, and bridges; areas affected by gully erosion; sites affected by water logging and flooding; and sites where efforts have been made to implement different soil and water conservation measures along a 5 kilometer radius from the main route. The survey was carried out in the period of July to September 2013.

The survey result revealed that a number of problems have been created due to water from roads which include: (a) erosion (downstream areas and road sides), (b) siltation/sedimentation of downstream, upstream, and side drainage areas, (c) water logging and damage on dwelling houses and on water harvesting systems (groundwater wells and ponds). In the 64 kilometre of roads there were 159 problems spots - close to 3 per kilometer. By and large these damage undermined the climate resilience of the road side communities.

**Effects gully erosion:** From a total of 118 culverts found along the road, gully erosion was recorded at downstream of 68 culvert locations. Gullies have a severe effect on agricultural activities; they reduce the water tables, affecting the availability of soil moisture and hence agricultural production. Once deepened, gullies decrease the accessibility of the land and can cause damage to all infrastructure (Frankl et al. 2012), including the road bodies that caused the gullying in the first place. The size of the surveyed gullies were found to be variable: 1 to 4.5 m deep, and 1.5 to 5m wide. The length ranged from 10m to over 500m. In 35 locations, road side erosion was recorded. Expansion of gullies and creation of new ones is common in the study area. In all the erosion affected sites, gullies have terminated after reaching the bedrock. Soil samples were collected from the field and analyzed in the laboratory to evaluate the in-situ moisture distribution across a gully site. Results of the analysis (Table 1) showed that the in-situ moisture content of the soil increased with increase in distance from the gully. Close to the gully the moisture content was no more than 8% but at 10m away from the gully the moisture content reached up to 45%. A reduction of soil moisture results in loss of productivity and increase expenditure in fertilizers to maintain yields as natural nitrogen fixation is closely linked to soil moisture (Morgan, 2005). Crops close to the gully have shown early maturation due to less moisture content in the soil, which has a direct effect on the yield.

**Table 1: Moisture distribution across a gully (LS= Left Side; RS= Right Side) in Freweign area, Tigray, Northern Ethiopia. Note that the depth of sampling was 0.5m and the soil type in the site is silty sand type. Samples were collected one day after a 50mm rainfall in the area.**

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Distance from gully (m)</th>
<th>Moisture content (%)</th>
<th>Soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS01</td>
<td>1</td>
<td>5</td>
<td>Silty sand</td>
</tr>
<tr>
<td>LS02</td>
<td>5</td>
<td>18</td>
<td>Silty sand</td>
</tr>
<tr>
<td>LS03</td>
<td>10</td>
<td>38</td>
<td>Silty sand</td>
</tr>
<tr>
<td>RS01</td>
<td>1</td>
<td>8</td>
<td>Silty sand</td>
</tr>
<tr>
<td>RS02</td>
<td>5</td>
<td>26</td>
<td>Silty sand</td>
</tr>
<tr>
<td>RS03</td>
<td>10</td>
<td>45</td>
<td>Silty sand</td>
</tr>
</tbody>
</table>

**Effects on siltation/sedimentation:** Sedimentation problems were recorded at 15 culvert out of 118 locations and at 5 road sides. The sediments have affected the road drainage systems and water harvesting structures like ponds and shallow groundwater wells. As a result, farmlands have been affected due to flooding and excessive accumulation of sediments on the farmland has forced farmers to plough and saw up to 3 times. In some cases, however, the accumulation of sediments has become an opportunity for sand mining; providing an extra source of income for some households. This could even be optimized by systematic reversal of the slopes of side drains.

**Effects on waterlogging:** at 37 locations along the road alignment water logging was recorded/documentated. Waterlogged areas include farm lands, grazing lands, and water harvesting schemes (like shallow groundwater wells). The causes for waterlogging observed during the field survey were due to one or a combination of the following: (a) inlet level of the culvert being higher than the upstream ground level, (b) outlet level of the culvert being lower than the downstream ground level, (c) reduction in pipe diameter due to siltation/sedimentation problems, and (d) absence of drainage systems and/or improper locations of drainage systems.
Effects on flooding: In 34 locations, water from culverts and road side drains had caused flooding of farmlands, ponds, and shallow hand-dug wells. The flooding caused damage to dwelling houses, silting-up of ponds and shallow groundwater wells. In one event in 2013 46 houses were destroyed. In the most flood prone land the uncontrolled flooding of farm land forced farmers to replant their land up to two or three times.

3. The positive impact of road water harvesting

Until the year 2013/2014, there was no systematic approach for road water harvesting in Tigray, as elsewhere in Ethiopia. There were however sporadic practices implemented as part of the soil and water conservation efforts. Since the year 2013/2014, efforts were made to introduce road water harvesting in a more systematic manner. Main practices of water harvesting from roads implemented in the study area thus far were financed by the government (particularly the Tigray Bureau of Agriculture and Rural Development) and implemented during the mass mobilization campaign of June-July 2014 when farmers provide labor days for watershed improvement. The main technologies and approaches implemented were: (a) use of pits/ponds to collect road side drainage, (b) channeling water from culverts and road side drainage into series of deep trenches, (c) use of borrow pits (for surface water storage and groundwater recharge), (d) channeling water from culverts and road sides to farm lands, (e) shallow groundwater development upstream of Irish bridges and fords and (f) reuse of borrow pits for water storage and groundwater recharge.

Use of ponds/pits to harvest water from roads: Since 2010, ponds have been constructed to collect water from any source including road-side drainages. Along the study route, five ponds have been constructed for surface water storage and groundwater recharge. It is common to have water from a culvert channeled into a properly design pond. The storage of rainwater can provide an extra source of water for irrigation, helping to improve the food security in the area.

Channeling water from bridges, culverts and road sides into series of deep trenches: In 7 locations along the route, water from culverts and road side drainages was channeled into deep trenches (Figure 2a). Deep trenches are often used to control runoff and enhance groundwater recharge processes. Measurement of the in-situ moisture of the soils around the trenches shows an increase in moisture content of the soil (up to over 100%) as compared to the previous year of the same season (Figure 2b).

Figure 2a. Water from a culvert is channelled into a deep trenches in Megab area, Tigray, Ethiopia. Hand-dug well downstream of these trenches is used for monitoring.
IRF Europe & Central Asia Regional Congress
September 15-18, 2015 – Istanbul Turkey

Figure 2b. In-situ moisture distribution in soils (before and after the construction of deep trenches at downstream of culverts in Megab area, Tigray, Ethiopia. Construction of the deep trench was done on June 2014. Monitoring was done for the period September-November for both years (2013 and 2014). (W1= Week one; W2=Week two; W3=Week three and W4=Week four).

Channeling water from culverts and road sides into farm lands: Diverting runoff (from road sides and culverts) into farm lands (Figure 3a) is one of the technologies implemented in Tigray. The purpose is to enhance availability of water for crop production. In-situ soil moisture measurement results (Figure 3a) shows that as compared to previous year of the same season, the soil moisture of the soil has improved after the interventions (by up to 100%).

Figure 3a. Diverting roadside runoff into farm lands as part of moisture conservation in Kiken area (along Mekelle-Wukro road), Tigray, Ethiopia.
Figure 3b. In-situ moisture distribution in soils (before and after the construction of structures that divert runoff from culverts into farm lands along the Mekelle-Wukro road (Kihen), Tigray, Ethiopia. Construction of the diversion structures was done on May-June 2014. Monitoring was done for the period September-October for both years (2013 and 2014). (W1= Week one; W2=Week two; W3=Week three and W4=Week four).

Channeling water from bridges, culverts, and road sides into check-dams: Though check-dam construction is a common water harvesting and gully treatment technique in Tigray, linking water from roads with check-dams is a new development. With the purpose of storing water from culvert, bridges and road sides and for the purpose of enhancing groundwater recharge check-dams are constructed in many parts of Tigray (e.g. Figure 4a). Results of the groundwater level measurement shows that due to the construction of the check-dam, the shallow well which used to have no yield in the dry season has become very productive even in the dry season (Figure 4b).

Figure 4a. Channelling water from a culvert into a check-dam is enhancing groundwater in Selekleka area, Tigray, Ethiopia.
Figure 4b. Groundwater fluctuation in Selekleka area, Tigray, Ethiopia (at downstream of a check-dam which was constructed in the period January-May, 2014). The check-dam is designed to store water from a box culvert. New groundwater is created at downstream of the box culvert and the construction of the check-dam has enhanced groundwater level in the area.

Shallow groundwater development upstream of Irish bridges: Along the Freweign-Hawzien-Abreha Weatsbeha-Wukro route, four Irish bridges and fords were identified. These structures can have multiple functions. The first obvious one is to allow road traffic to cross the dry river bed. The fords can however also double up as a sand dam, trapping coarse sediment behind them and creating small local aquifers that can store and retain water (Neal 2012).

Conversion of borrow pits to water storage and recharge structures: close to Freweign catchment run-off was concentrated in a large cross drainage structure with three culverts. This new structure created a constant threat and fear of flooding and in one event 46 houses were destroyed. To resolve this problem it was proposed to channel the run-off through a 3 kilometer long canal to the river, but this would require considerable land acquisition. A more cost effective solution was used when a 250 meter long canal was excavated to the borrow pit which was converted 5000 cubic meter storage and recharge pond.

4. Conclusions: redefining climate resilience from roads

The potential for water harvesting from roads and in particular roaded catchments in Tigray and in many parts of Africa is high. Road development is one of the major public investments and significantly alters the hydrology. If not managed properly, water from roads causes problems to the surrounding areas and to the roads themselves. Through the proper integration of road development with water harvesting, the negative effects of water from roads could be turned into positive. In Ethiopia and in many part of Africa there is shortage of water during dry seasons and water harvesting remains one of the most important considerations for enhancing agricultural productivity. For example, the 64 kilometer road that was investigated passes almost through the water divide in Tigray: about 1.34 Million Cubic meter of surface water could be harvested without major investment. At the same time water-related road maintenance costs can be reduced, which now stand at 35%, a figure that may be higher if road water-related land-slides are included.

In the 2014 campaign described in section 3 adjustments were made that made use of the road as it was and saw a large number of water harvesting structures implemented. There is a need to go one level up and to consider modified road design that optimize both transport functions as well as the beneficial use that roads can have on water management. In many areas – but it semi-arid mountain or flood plain this is essential. There a number of recommendation so as to integrate road development with water harvesting:

- When planning road development in a certain catchment it is important to look at options on how water from a road (drains, culverts, bridges, fords, road surface) could be harvested for economic benefit of the local communities. This concerns both paved and unpaved roads. In paved road the beneficial use of water from cross drainage structures is a main opportunity. In unpaved roads the development of water bars and led out drains can be combined with water harvesting and create the incentive for maintaining these essential drainage structures.
• The location, alignment and size of drainage systems (culverts, road side drainages, etc) and in some cases the entire alignment of the road should be designed with the objective of harvesting water from roads either to be collected into surface water reservoirs or used for groundwater recharge. This requires an understanding and evaluation of the surface as well as subsurface geohydrology of the area.

• There is large scope to optimize the designs of road bodies: in cross drainage, in road subsurface, in fords, in systematic capture of road-side springs. Borrow pits development (for the extraction of construction material) for instance is one of the major activities in road construction. It is advisable that the location and size of the borrow pit to be developed is identified during/or even before the final design of the road is made. Based on this the locations of culverts and even the road alignment could be designed in such a way that water from roads (road side drainages, culverts, bridges) is channeled into borrow pits and they are shaped accordingly. Using borrow pits for surface water storage as well as groundwater recharge is one of the best options in road design and construction.

• Water harvesting from roads could be implemented effectively if road development in a certain catchment is considered as part of the watershed/catchment development plan. Through such approach, the possible negative effects of water from roads and options for mitigating such problems through water harvesting and natural resources management could be implemented.

• Water harvesting from roads involves multi-stakeholders. For water harvesting from roads to be implemented effectively there should be strong linkages and cooperation among the sectors through a more powerful body but with clear tasks and responsibilities for each stakeholder. In the program in Tigray it become clear that the cooperation and linkages among the stakeholders at field level is essential. There is a need to include road side communities in the design and implementation of the road and water programs and also to regulate access to the new water resources generated for male and female community members.

There has been recent attention to make roads more climate resilient. In some work design standards have been proposed to be adjusted to make road bodies and drainage system better able to deal with higher temperatures and steeper floods. This has however often led to road designs that are far more costly – making it difficult to expand the coverage of the road network, which is essential for many developing areas.

We believe that the above – to make the roads themselves more climate resilient - is a partly misguided approach. It makes more sense to develop roads so as to optimize their hydrological potential for water harvesting and others. This will very positively contribute to water security in view of climate change and improve the resilience of those living close to the roads. It will turn the negative impact on climate resilience of road-side communities into a positive and contribute to productive growth. At the same time rather than increasing costs, it will importantly reduce the cost of road maintenance.

Acknowledgements

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References


Our country which is being located on the passage corridor of international transportation road net, aiming intercontinental logistics center depending on geopolitical position and national and international public demands are forcing our organization to make the realization of split roads and motorways. Since our country's geography containing adverse geological conditions, being within an active earthquake zone, large scale rock and soil landslides and flooding and natural disaster risks and all these infrastructure works has to be constructed on mountainous areas and passages, the increasing environmental sensitivity require the tunnel options stand out in forming the desired project standards. In performing the goals of General Directorate of Highways the development in prediction and design of planned roads had brought the necessity of constructing of some important constructions which are followed by world countries. Some of the latest tunnel constructions which were completed and ongoing in our country are North Marmara Motorway located on the route which is the first four-lane highway tunnel in the world (Sultuoe and River Tunnel), the Istanbul-Izmir Motorway, the 3-lane Samanli and Selcukgazi the route tunnels, Izmir Bay Crossing artificial island and the immersed tunnel structure, new Zigana Tunnel, Ovit Tunnel, Kop Tunnel, Kirik Tunnel, Izmir Konak Tunnels, Sabuncubeli Tunnel, Ilgaz Tunnel, Zonguldak City Pass Tunnel (Mithatpaşa, Saba, and Üzülmez Tunnels), Erkenek and Karahan Tunnels, Geminbel Tunnel, Istanbul-located in Göksun route road tunnels (T0, T1, T2, T3 and Caglayan-Tekir Tunnel) and the Black Sea Coastal Road Tunnel can be sampled. When it looks at tunnel construction projects and inventory; Our traffic light tunnel 244 (219 Km), our tunnel construction work in progress 133 (329 Km) and the planned number of 267 is the length of the tunnel which is 828 kilometers. Accordingly, the rate of tunnels under construction to total tunnel length is 25% and the planned tunnel length to total tunnel length constitutes 60%. This data can be regarded as an indicator that we are on the start line to road tunneling. In Tunneling projects and construction work on highways New Austrian Tunneling Method (NATM) is used. On completed road tunnel works the general rock excavation class had been realized as 5%A2, 10% B1, 15%B2, 35%B3, 1%C1, 20%C2, 10% C3, 3%C4 and 1%C5 respectively depending on the geological conditions. In this point of view route planning which is effective in development of road tunneling, exhibiting the structural behavior characteristics of a rock tunnel in the entrance and exit portals and alignment excavation sections of our tunnels in project and construction phases and development of application projects for the solution of adverse geological and geotechnical problems encountered during construction work thus the establishment of the institution's tunneling memory, several technical issues, including the creation of electronic documents and archives system, are among the objectives of our Organization.
KARAYOLU ULAŞIM MODUNDA TÜNELCİLİĞİN YERİ, GELİŞİMİ VE HEDEFLERİ,
TÜRKİYE JEOLojiK KOŞULLARININ TÜNELLERİN PROJE VE YAPIM ÇALIŞMALARINA
OLAN ETKİLERİ

Ahmet ŞİRİN1

(1) Karayolları Genel Müdürlüğü, Araştırma ve Geliştirme Dairesi Başkanlığı,
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1. GİRİŞ

Ülkemizin uluslararası ulaşım yol ağlarının geçiş koridoru üzerinde olması, jeopolitik konumuna bağlı olarak kıtalararası lojistik merkezi olma hedefi, ulusal ve uluslararası kamuoyu beklentileri Teşkilatımızın bölünmüş devlet yol ve otoyol hedeflerinin gerçekleştirilmesini zorunlu kılmaktadır. Ülkemizin hedeflenen ulaşım politikalarında 2023 ve 2035 hedeflerine bağlı olarak şehirlerarası karayolu ve otoyol planları yapılmıştır (Şekil-1).

Şekil-1: Karayollarının 2023 Bölünmüş Yol ve Otoyol Hedefi.

2. KARAYOLLARINDA TÜNELCİLİK

2.1 Planlama ve Tünelcilik

2.2 Ülkemizin Jeolojik ve Tektonik Yapısının Yol Yapımına Olan Etkileri ve Topografik Zorluklar

2.2.1 Jeolojik Koşullar ve Yapısal-Tektonik Etkenler


- Pontidler (Istranca Napı, İstanbul Napı, Küre Napı, Bayburt Napı, Sakarya Kıtasi)
- Toridler (ve Anatolid) Platformu
- Arap Platformu ve
- Doğu Anadolu Yığışım Karmaşığı


Şekil-2: Türkiye Jeoloji Haritası (MTA-2015)
Şekil-3: Türkiye'nin plaka tektoniği ile ilişkisi.

Şekil-4: Türkiye'de M>5 olan aktif depremlerin dağılımı ve plakaların yıllık hareketleri.

Şekil-5: Türkiye'de Kuzey Anadolu Fayına bağlı sismik aktivitesinin görünümü ve deprem risk haritası.
2.2.2  Jeomorfolojik Koşullar ve Topografik Etkenler


- Yüksek dağlık alanlar (sıradağlar, tek dağlar ve kültürel dağlar, 1000-6500 m yüksekliğe sahip),
- Plato alanları (Ülkemizin Kuzey ve Güneyinde yer alan dağların ortasında kalan kesimi genelde ortalama yüksekliği 1000 m'yi bulan plato görünümündedir. Oluşum şekillerine göre; Peneplen Platoları, Karstik Platolar, Lav Platoları, Hafif Yarımboğazlık Platoları olarak adlandırılır.
- Ovalar; Türkiye'de ovalar Ülkemizin ancak %8'i düzlük alan. Kıyı bölgelerimizdeki ovalar genelde deniz seviyesinden başlamak üzere 200-300 m. yüksekliğe çıkarırken, yer yer 15-25 ile iç kısımlara doğru 120-150 km kadar girdikleri de olur.
Ülkemiz coğrafyası yüksek dağlık alanları içermekte olup ortalama yükseltisi 1131 metreden fazla olan bir ülkedir (Şekil-9). Karayollarında olumsuz kış koşullarında trafiğin güvenliğinin sağlanabilmesi için karla mücadele kotleri 600 m kotlarından başlayarak proje tasarmlarına 850 m kotlarından sonra kar hendeği projesi ilave edilmektedir.

2.3 Tünel Yapım Metodolojisi
Karayolları Genel Müdürlüğünün 1997-2006 ve 2013 Karayolları Teknik Şartnamesi kapsamında yer alan tünel proje ve yapım şartlarının tariflendığı şartname ile; NATM [N(ew) A(ustrian) T(unneling) M(ethod)] metodu ile tünel açma yöntemi esas alınmaktadır (Tablo-1). Bu yöntemle de;

- Kayalarda delme-patlatma ile; üstyarı – altyarı şeklinde (A1 – A2 – B1 – B2 – B3),
- Zayıf – çok zayıf kayalarda ise delme patlatma + makineli kazı; üstyarı – altyarı ve taban invertli kazı,
- Baskılı kaya / zemin ortamlarında; bölünmüş veya tam kesit üstyarı – bölünmüş ve tam kesit altyarı ve bölünmüş veya tam kesit invert kazı metotları ile C2 – C3 ve C4 sınıfları destek uygulanmaktadır.

Tablo-1: NATM Metodu Kaya Sınıfı ve Destekleme Öngörüsü (Rabczewicz ve KTŞ-2013).
2.4 Tünel Proje Çalışmalarında Yapılan Jeolojik-Jeoteknik Çalışmalar

Karayolları Teknik Şartname içeriğinde yer alan tünel projelendirme çalışmaları kapsamında yapılan jeolojik - jeoteknik etüt çalışmalarında 3 önemli aşama yer almaktadır.

• 1/25000 Ölçekli Tünel Jeolojik-Jeoteknik Elverişlilik Etütü; Bu kapsamında tünel güzergahının portal giriş ve çıkışlarının heyelanlı sahada olup olmadığı, ülkemizin olumlu tektonik yapısı ve aktif deprem kuşakları içerisinde olması nedeniyle aktif fay hatlarını kesip kesmedikleri ve/veya zorunlu güzergah geçişleri ise aktif fay hatları ile yapısal ilişkileri ortaya koyularak tünel yapılabilirliği teknik ve ekonomik yönden ortaya koyulduğu bilgileri içeren önemli bir aşamadır (Şekil-10).

• 1/5000 Ölçekli Tünel Ön Proje Jeolojik-Jeoteknik Etütleri; Bu kapsamında tünel giriş ve çıkışları tünel delme kesimlerine ait yapılabılırlikler ve proje büyüklükleri ölçeğinde ortaya koyularak kesin proje aşamasında daha detaylı olarak çalışılması gereken kesimlerin de tespit edildiği aşamadır.

• 1/1000-1/2000 Ölçekli Tünel Kesin Proje Jeolojik-Jeoteknik Etütleri; Tünel ekseninin yatay ve düşey olarak kesinleştirildiği, portal giriş-çıkış bölgelerinin stabilite ve geometrik olarak yapı-jeolojik ortam (kaya-zemin) ilişkilerinin detaylı mühendislik jeolojisi, sondaj, yerde deneyler (in-situ tests), jeofizik etütler ve laboratuvar deney sonuçları ile İdarenin onaylı jeolojik-jeoteknik plan, profil ve enkesitlerinin kesinleştirildiği ve buna göre uygulama projelerinin oluşturulduğu aşamayı tarih etmektedir (Şekil-11).

Şekil-10: Tünel yaplarının güzergah standartlarına olan katkısı ve sağladığı ekonomik fayda örneği.

2.5 Yapım Çalışmalarda Yapılan Jeolojik-Jeoteknik Çalışmalar
Kesin proje çalışmaları sonrasında ortaya koyulan tünel jeolojik-jeoteknik profiline göre oluşturulan kaya sınıflama ve destek sistemlerinin tünel yapım esnasında gerçekleşmesinin tünel yapım esnasında yapılacak jeolojik-jeoteknik çalışmalar aşağıdaki şekilde yapılmalıdır.

2.5.1 Jeolojik Haritalama ve Mühendislik Jeolojisi Çalışmaları
- Tünel Ayna Jeolojik Haritalama Formu ve Jeolojik Açılım Haritasının Yapılması (Şekil-12),
- Mühendislik jeolojisi verilerinin tutulması ve jeomekanik özelliklerinin ortaya konulması,
- Q, RMR ve NATM kaya sınıflarının tespit ederek belirlenmesi gerekmektedir.
Aynanın jeolojik, yapısal ve jeomekanik özelliğinin tespitinde yapılan incelemede 3 farklı inceleme uygulanmaktadır.

a) Detaylı inceleme; Bu incelemede tünel kayasının detaylı stratigrafik, litolojik ve yapısal özellikleri ortaya koyulmasına yönelik mühendislik jeolojisi verileri; sertlik, çimentolanma, granülometri, alterasyon, süreksizlik özelliklerini (süreksizlik tipi, pozisyonu yada yönelimi, geometrisi, dolgu durumu, JRC (Joint Roughness Coefficient), JCS (Joint Comprehensive Strength), yeraltı suyu ve çatlak suyu durumu ve kazı esnasındaki kaya davranış (ani göçme, gevrek, kırılgan, sümme, şişme gibi özellikler) kayıt altına alınmalıdır.

b) Ön İnceleme; Aynanın fotoğraflı görüntüsü diye adlandırılan tünel kayasının niteliksel olarak litolojik, yapısal ve stratigrafik kayaç özellikleri ortaya koyulur. (a) maddesindeki jeolojik verilerin deşifre edilmesi durumunda geçerlidir.

c) Ayna Kayıtları; Ölçekli jeolojik haritalama yapılmasını ve ayna fotoğrafinin veya/veya gerekli indeks haritalarının alınmasını sağlamanın önemini gidermektedir.

Şekil-12: Tünel portal şevleri, tünel ayna jeolojik harita kayıtları ve jeolojik açılım haritası örneği.

2.5.2 Jeoteknik Ölçümler
Tünel yapım aşamasında proje öngörülerinin takibi ve deformasyon toleranslarının radyal kapanım olarak takip edilmesi, deścişleme – tünel kayası etkileşimlerinin takibi için tünelde yapım çalışmaları ve servis ömrü boyunca deformasyon ölçümünün takibi büyük önem taşımaktadır. Öncelikle her tünel projesinin kendi tasarım kriterlerine göre Deformasyon Ölçüm İstasyonlarının oluşturulması ve izleme programlarını oluşturması gerekmektedir [Şekil-13 (a, b)].

Şekil-13 (a, b): Aç-kapa ve sağ tünelde üç boyutlu deformasyon ölçümü uygulama şekilleri örneği.
3. SONUÇLAR

Tünel projelendirme çalışmaları ve sonrasında tünel yapım çalışmalarını aşamasında tünel kayasının kazı ve destekleme tipinin belirlenmesinde ayna jeolojik haritalaması ve uygulanan destek-deformasyon ilşikilerinin ortaya koyulmasıyla formasyon ölçümü önemli bir yer tutmaktadır. Ülkemizin olumsuz jeolojik yapısına bağlı olarak yatay ve düşey kaya-zemin geçişlerinin çok sık değişiklik göstermesi, aktif deprem kuşakları içerisinde yer alması, çok eğimli ve dalgalı arazi morfolojisi sunması gibi birçok faktör nedeniyle yerine mekanik sondaj, yerinde deneyler ve diğer araştırma çalışmalarının yapılması gibi nedenlerle tünel kayasının yapım aşamasında jeolojik açıdan takibi ve davranışını proje yapım maliyetlerine açısından büyük önem taşımaktadır.

Tablo-2'de ülkemizdeki yapılan tünellerde gerçekleşen kaya sınıfları, Grafik-1'de ise destek sınıflarına göre ortalamada maliyetler görülmektedir. Grafik-4 ise, yapı devam eden ve planlanan tünellerin beklenen ortalamada gerçekleştirmeye maliyetlerini göstermektedir.

Ülkemizde karayolu tünellerinin geliştirilmesi adına tünel paydaşlarının sektörel anlamda aşağıdaki hususların değerlendirilmesi önerilmektedir.

- Mülteahhit ve İdare adına iş mahallinde yeterli ve tünel konusunda uzman personel bulunması,
- Tünel giriş Yapılarının jeolojik modellerinin ortaya konulmasında detaylı etütlerin her koşulda titizlikle yapıldığı, özellikle dünyada ilk kez 4 şeritli tünel yapımının projelendirme ve yapım teknolojisinin Teşkilatımız ve Türkiye tüneller sektörüne geniş ölçülü kesintisiz olarak teknik bilgi transferinin yapılması,
- Ülkemizde karayolu tünelleri uygulanan NATM Uygulamalı Tünel Teknik Şartnamesi esaslarının, dünyada yapılan tünel proje ve yapım süreçleri ile karşılaştırıldığında yeniden yorumlanmasına ve yeni metodolojilerinin oluşturulmasının gerekliliği bulunmaktadır. Bu anlamda; Tünel Tünelciliği (Rock Tunneling), Zayıf Zemin Tünelciliği (Soft Soil Tunneling), Açı-Kapa Yapılar (Cut and Cover), Batırm Tünelleri (Immersed Tunnel), TBM Tünelciliği, Tam Kesit Ayna (Full Face Tunneling), Hücresel Kemer Tipi Tünel Açma (Tunneling With Circular Cell Method) gibi metodların ayrı ayrı veya birlikte uygulandığı diğer özel tip tünel proje ve yapım metodolojilerindeki teknoloji transferlerinin gerçekleştirilerek ülkemiz şartlarına uyarlansması gerekmektedir.

Teşkilatımız 2023 ve 2035 hedeflerine bağlı olarak yapım programında olan 329 km tünel inşaatı ile proje programında yer alan 828 km uzunluğundaki tünellerin proje ve yapım gerçekleştirilmesi; yapılan tüm bu projelerde dikkate alınan karayolu tünellerinin son derece karmaşık jeolojik yapının ve sismik aktivite etkisi altında bilimsel, teknik ve ekonomik gelişiminin dünyada ölçüğünde daha ileri seviyelere ulaştırılmasını ve projelerin rehin etmektedir.
ABSTRACT

Construction of tunnels in Turkey started in 1950s. The main purpose of these tunnels were to construct a protection for the passengers due to landslide and snow slide disasters. Turkey increased construction of highways in late 1980s and as a result of this new tunnel projects started with New Austrian Tunneling Method (NATM) which was considered as greatly long tunnels at that period of time. Hence, Turkish engineers encourage themselves for construction of longer tunnels than completed before.

In the early 1990s Turkey began building the twin-tube motorway tunnels in state highways, and the experience transferred to the provincial road tunnel construction. Here, one of the most important transmissions are electro-mechanical works. In the 2000s divided highway projects with 5 km of tunnels were announced and after 2010, 10-15 km in length tunnels started to be tendered. The important target which consist of opening of tunnels in the North-South axis in Turkey's 2023 strategic plan is the most important factor of these developments.

Turkey in the last 20 years made numerous tunnels and to begin construction of the 10 kilometer long tunnels that caused the work on the tunnel safety has been increasing in importance. The minimum tunnel safety requirements of infrastructure measures on the basis of Motorways for road tunnels in Turkey in 2005 were concluded with multi-disciplinary commission to study the circular prepared for the General Directorate. The circular issued in 2004, on the basis of the European Union's Trans-European Road Network for 2004/54/EC directive.

Tunnel Projects should be designed according to the minimum safety requirements. Not only after the construction of tunnel opened to traffic maintenance, but also operation period and activities should be considered in the design stage.

The classification of each tunnel should be determined by a team of experts according to the circular. As a result of both domestic and overseas, technological innovations must be continuously monitored and tunnel safety criteria should be updated.

1.TÜRKİYE DE KARAYOLLARı TÜNELLERİNİN TARİHÇESİ


2000’li yıllarda girdiğiımız yıllarda 5 km ve üzerindeki tuneller üzerinde çalışılırken, 2010’lu yıllarda artık 10 km ile 15 km arasında değişen tuneller hâle edilmeye başlanmıştır. Uzun tunellerin yapımının en önemli nedenlerinden biri, Türkiye’nin 2023 yılı stratejik planlamasında yer alan kuzey-güney akşların açılması hedefidir.

2.TÜRKİYE DE KARAYOLLARı TÜNEL GÜVENLİK DİREKTİFİ

Türkiye’de son 20 yılda çok sayıda tünel yapımı ve 10 kilometreden uzun tunellerin yapımına başlanması, Tünel Güvenliği konusundaki çalışmaların önemini daha da artırmıştır.

Güvenliğin ilk aşaması olarak tünel projeleri minimum güvenlik gereksinimlerine göre dizayn edilmelidir. Tünelin yapım aşamasında alınan güvenlik önlemleri önemli olduğu gibi, trafıge açıktan sonra bakım-işletme faaliyetleri aşamasında da güvenlik, projelendirme aşamasında düşünülmelidir. Genelgeye göre her tünelin sınıflandırılması uzman bir ekip tarafından belirlenmelidir. Sonuç olarak gerek yurtiçi gerekse yurtdışında teknolojik yenilikler takip ederek tünel güvenliği kriterleri devamlı güncel tutulmalıdır.

Şekil 1. İlk yapılan çığ tüneli ve günümüzde yapılmış tam donanımlı tünel örneği

3. TÜNEL GÜVENLİĞİNİ ETKİLEYEN FAKTÖRLER

ALTYAPI

Tünel güvenliğini etkileyen altyapı önlemleri; tüp ve şerit sayısı, tünel geometrisi, aydınlatma, havalandırma, kaçış yolları ve acil çıkışlar, acil servisler için erişim, acil istasyonlar, acil güç kaynağı, cepler, drenaj, su temini, izleme sistemleri, haberleşme sistemleri, yol işaretleri, tünel kapatma ekipmanı, ekipmanın ateşe dayanıklılığı ve kontrol ünitesi olarak gruplandırılır. Altyapı önlemleri proje ve yapım esnasında gerektiği şekilde ele alınmadığı takdirde tünel işletmeye geçtiğinde telafisi zor durumlarla karşılaşılabilir.

İSLETME

Tünel güvenliğinde bu maddeler ek olarak; tünel işleten idare yetkili makamlarla (polis, itfaiye, ambulans) genel koordinasyon, acil durum planlaması, kaza ve olayların yönetimi, tünelin alternatif güzergâhları belirlene ve gerektiğinde yönlendirme, kontrol merkezinin faaliyetleri, tehlikeli maddelerin taşıma ve taşınması gibi tünel işletme sürecinde de önlemler alınmalıdır.

Avrupa'da meydana gelen büyük tünel kazaları sonrası tünellerin onarımı ve

4. AVRUPADA KARAYOLO TÜNEL GÜVENLİĞİ

yeniden güvenlik ekipmanlarının tesisi, daha sonra tünelin kapanmış olmasından kaynaklanan dolaylı maliyetler, çevresel zararlar ve tazminatlar Avrupa Ekonomisini büyük ölçüde etkilemiştir.


Yapılan her tünel kendi başına mühendis farklı özellikler gösterir ve Avrupa’da tünel alan ülkeler tünel güvenliğini farklı kriterlere göre değerlendirirken AB Direktifinin yürürlüğe girmesi ile yeni yapılan tünelde bu kriterlere uygun, güvenliğin yetersiz kaldığı mevcut tünelde ise bu kriterlere bağlı olarak iyileştirme çalışmaları devam etmektedir.

5. TÜRKİYEDE KARAYOLU TÜNEL GÜVENLİĞİ


Karayolları Genel Müdürlüğü’nün 2005 yılında yayımlanan Genelge dünyada bu uygulamalarla rehber olarak kullanılan aşağıdaki kaynakları incelemiş;  
- Avrupa Parlementosu ve Konseyi’nin 29.04.2004 tarih ve 2004/54/EC sayılı Trans-Avrupa Karayolu Ağı Tüneli İçin Minimum Güvenlik Gereksinimleri,  
- Tünel için Acil Durum Tesisleri Şartnamesi (Japonya, 1997)  
- UNECE-Karayolu Tüneli Uzmanlar Grubu’nun Tavsiyeleri Nihai Rapor (TRANS/AC.7/9, 2001)  
- CIE (Uluslararası Aydınlatma Komisyonu)

6. İSTANBUL-BURSA-İZMİR OTOYOLUNDA YAPIMI DEVAM EDEN TÜNELLER

**Samanlı Tüneli:** Gebze – Orhangazi – İzmir Otoyolu Projesi’nde yer alan üç otoyol tünelinden biri olan Samanlı Tüneli sağ tüp 3.591 m. ve sol tüp 3.586 m. olacak şekilde 3’er şeritli 2 tüp şeklinde projelendirilmişdir. Samanlı Tüneli hizmete açıldığında Türkiye’nin en uzun otoyol tüneli olacaktır. Tünelin her bir tüpü; 3x3,75 m. Şerit ve 2x0,375 m banketten oluşan 12 m. lik platform genişliğinde sahiptir. Tünel boyunca 500 m. de bir olmak üzere 4 adet yaya, 2 adet Araç Geçişi olmak üzere 6 adet Acil Geçiş bulunmaktadır.

**Şekil 3. Samanlı Tüneli yapım çalışmalarları**

**Selçukgazi Tüneli:** Gebze – Orhangazi – İzmir Otoyolu Projesi’nde yer alan üç otoyol tünelinden bir diğeri olan olan Selçukgazi Tüneli’nin yapımına, otoyolun 76+720 ile 77+770’üncü kilometreleri arasında devam edilmektedir. Güzergahta görülen bir takım geoteknik sorunlarla birlikte bazı kesimlerde %5’in üzerindeki boyuna eğimler nedeniyle varyant çalışmalarına alternatif olarak tünel yapımı tercih edilmişdir. Zemin koşullarında çalışan bir tünel olup, kaya formasyonu oldukça azdır.

**Riva Tüneli ve Çamlık Tüneli:** Kuzey Marmara Otoyolu Projesi Odayeri-Paşaköy kesimi (3. Boğaz Köprüsü dahil) projesi kapsamında yapımına devam edilmekte olan Riva Tüneli (kuzey tüp 626 metre, güney tüp 561 metre) ve Çamlık Tüneli (kuzey tüp 600 metre, güney tüp 700 metre) 4’er şeritli 2 tüp şeklinde projelendirilmiştir. Riva ve Çamlık tünelerin Türkiye’nin en geniş otoyol tüneli olma özelliğini taşıyor. Tünel enkesitinin 220 m² olmasından dolayı kazi ve destekleme çalışmaları 6 farklı aşamada tamamlanmaktadır.

7. SONUÇ VE ÖNERİLER

daha da önemli hale getirmiştir. Bundan sonra atılan adım Avrupa Birliği Direktifi ile Türkiye’de hazırlanan genelgenin farklılıkları ve eksikliklerinin biran önce belirlenip teknik çalışmanın bitirilmesidir.


Coğrafi yönden dağlık arazi yapısına sahip olan ülkemizde Kuzey-Güney akslarında açılan koridorlarla buradaki dağları aşmak için yeni ve daha uzun tünelin yapımı gerektiği ve bunun doğal sonuç olarak tünel güvenliğinin önemini ön planda çıkarmaktadır.

İstatistiklere göre tünelde kazalar daha az geçecekmesine rağmen, tünel kapalı yapılmasına nedeniyle yeterli güvenlik tedbirleri alınmadığında kaza sonrası bir de yangın çıkarsa çok ciddi sonuçlarla karşılaşmaktadır.

Karayolu tünelinde minimum güvenlik kriterlerinin sağlanması, mevcut tünelin eksiklerinin belirlenip bu kriterler doğrultusunda gerekli tedbirlerin alınması, yapılmış planlanan tünelin her aşamasında (proje, yapım, işletme) bu kriterlerin göz önünde bulundurulması önemlidir.
**TÜNEL GÜVENLİĞİ PROJE KRİTERLERİ (1)**

● : Zorunlu  ○ : Zorunlu değil  *
: İstisnalar ile birlikte zorunlu ◊ : Tavsiye edilir

<table>
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<th>ÖZETİ</th>
<th>Trafik ≤ 2000 araç/şerit (2)</th>
<th>Trafik &gt; 2000 araç/şerit (2)</th>
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<td>&gt;1000m</td>
<td>500 m-1000m</td>
<td>1000m-3000m</td>
<td>&gt;3000 m</td>
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</tbody>
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**Yapısal Önlemler**

<p>| Tüp Sayısı ≥ 2 | 1 |  |  |  | 15 yıllık trafik tahmini 10000 araç/şerit’i aştığı öngörürlüğe zorunludur. (3) |
| Eğim ≤ % 5 | 2 | * | * | * | * | * | Coğrafi koşullar uygunsa zorunludur. |
| Yaya Yolları | 3.1, 3.2 | * | * | * | * | * | Acil şeritler yoksa, 3.1 maddesinde açıklanan koşul sağlanmadıkça zorunludur. |
| En fazla her 500 m’ de Acil Çıkışlar | 3.3, 3.9 | ○ | ○ | * | * | * | Mevcut tünellerde yapılması her bir duruma göre değerlendirilecektir. |
| En fazla her 1500 m’ de acil servisler için Enine Geçişler | 4.1 | ○ | ○ / ● | ○ | ○ / ● | ● | Tünel 1500 m’ den uzun ikiz tüplü ise zorunludur. |
| Her bir portal çıkışında Orta Refüj Geçışı | 4.2 | ● | ● | ● | ● | ● | Coğrafi imkanın olduğu ikiz veya çok tüplü tünellerde zorunludur. |
| En fazla her 1000 m’ de Cepler | 5 | ○ | ○ | ○ | ○ / ● | ○ / ● | 1500 m’ den uzun ,acil şeritleri olmayan, yeni iki yönlü tüneller için zorunludur. 1500 m’ den uzun mevcut tünellerde analize bağlıdır. Yeni ve mevcut tünellerde kullanılabılır extra tünel genişliğiine bağlıdır. |
| Yanıcı ve Toksik Madde Drenajı | 6 | * | * | * | * | * | Tehlikeli madde taşınmasına izin verilen tünellerde zorunludur. |
| Yapının Yangına | 7 | ● | ● | ● | ● | ● | Lokal bir çökmenin afetle sonuçlanabileceği |</p>
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<td>En fazla her 150 m’de</td>
<td>10</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Havalandırma</td>
<td>En fazla her 250 m’de</td>
<td>11</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Su Temini</td>
<td>En fazla her 250 m’de</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Su Temini</td>
<td>En fazla her 250 m’de</td>
<td>11</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>İşaretlemeler</td>
<td>12</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kontrol Merkezi</td>
<td>13</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>İzleme Sistemi</td>
<td>Görüntü</td>
<td>14</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>İzleme Sistemi</td>
<td>Otomatik Olay Algılama ve/veya Yangın Algılama</td>
<td>14</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tünel Kapatma</td>
<td>Girişlerden önce trafik sinyalleri</td>
<td>15.1</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*İkili yönlü ve kontrol merkezi olan tünellerde zorunludur.*

*İçerisinde telefon ve iki söndürücü bulunur. Yeni tünellerde en fazla 150 m de bir, mevcut tünellerde en fazla 250 m aralıklarla bulunur.*

Yoksa, başka bir şekilde yeterli su kaynağı sağlanması zorunludur.

*Acil haberleşme telefonu, yangın tüpü, cep, acil çıkışlar gibi kullanımcılara sunulan tüm tesisler de dahil olmak üzere gerekli yatay ve düşey işaretlemeler yapılacaktır.*

*Birkaç tünelin izlenmesi tek bir kontrol ünitesinde merkezileştirilebilir.*

*Kontrol merkezi varsa zorunludur.*

*Bu iki sistemden en az biri kontrol merkezi olan tünellerde zorunludur.*
<table>
<thead>
<tr>
<th>Ekipmanı</th>
<th>Tünel içerisinde en fazla her 1000 m’ de trafik sinyalleri</th>
<th>15.2</th>
<th>◯</th>
<th>◯</th>
<th>◯</th>
<th>◯</th>
<th>◯</th>
<th>◯</th>
<th>◯</th>
<th>◯</th>
<th>◯</th>
<th>◯</th>
<th>Kontrol merkezi varsa ve uzunluk 3000 m’ yi aşıyorsa önerilir.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haberleşme Sistemleri</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acil servisler için Tekrarlı Radyo Yayını</td>
<td></td>
<td>16.1</td>
<td>◯</td>
<td>◯</td>
<td>◯</td>
<td>◯</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Tünel kullanıcıları için Acil Radyo Mesajları</td>
<td></td>
<td>16.2</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Tünel kullanıcıları için tekrarlı radyo yayını ve kontrol merkezinin olduğu yerlerde zorunludur.</td>
</tr>
<tr>
<td>Sığınaklar ve çıkışlarda Anons Sistemi (Hoparlörler)</td>
<td></td>
<td>16.3</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Tahliye durumındaki tünel kullanıcılarının dışarya çıkmadan önce beklemeleri gereken yerlerde öğenin sığınaklarda zorunludur. Ayrıca tünel boyunca girişim oluşturmayacak ve işitilebilir bir ses seviyesi sağlayacak şekilde gerekli aralıklarla tesis edilmelidir.</td>
</tr>
<tr>
<td>Acil Güç Kaynağı</td>
<td></td>
<td>17</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>En azından tünel kullanıcılarının tahliyesi süresince, kaçınılmaz olan güvenlik ekipmanlarını işlevsel tutacaktır.</td>
</tr>
<tr>
<td>Yangına Dayanıklı Malzeme</td>
<td></td>
<td>18</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Gerekli güvenlik fonksiyonlarını sürdürmeyi amaçlayacaktır.</td>
</tr>
</tbody>
</table>

(2) Trafik hacmi olarak tünelin trafiğe açıldığı tarihdeki araç/sherit sayısı dikkate alınarak değerlendirme yapılacaktır. Hesaplamada her araç bir birim kabul edilecektir.
(3) Sadece tüp sayısının tespitinde esas alınacaktır.
KAYNAKÇA:


ZAYIF KAYA KOŞULLARINDA, GENİŞ AÇIKLIKLI TÜNEL YAPIMI,
KUZEY MARMARA OTOYOLU ÇAMLık TÜNELİ ÖRNEĞİ

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ÖZET

İstanbul’un Asya ve Avrupa yakasını 3. Boğaz Köprüsü ile birleştirecek olan Kuzey Marmara Otoyolu’nun, Poyrazköy – Paşaköy kesiminde, Km: 103+830 – 104+456 arasında Riva Tüneli, Çamlık – Reşadiye bağlantılı yolu, Km: 3+715 – 4+379 arasında da Çamlık tüneli bulunmaktadır. Kazı ve destek sistemleri Yeni Avusturya Tünel Açma Yöntemi (NATM)’ne göre projelendirilen tüneller, farklı uzunluklardaki ikişer adet tüpten oluşmaktadır. Riva ve Çamlık tünelinin her bir tüpü 4 şeritli olup; tüp uzunlukları 552 m (kuzey) ve 651 m (güney) civarında, kaza genişliği 21,80 m, nihai tünel genişliği ise 15,50 m’dir. Riva tünelinin ortalama derinliği 50 m dolayında olup, örtü kalınlığının en fazla olduğu yerde yükseklik 75 m civarındadır. Çamlık tüneli üzerindeki örtü kalınlığı ise en fazla 60 m seviyelerine ulaşmaktadır.


Yapım çalışmalarını devam etmekte olan Riva tüneli, NATM’ye göre B2 ve B3 kaza ve destek sistemleri ile 4 aşamada kazılırken, daha zayıf zemin formasyonlarından geçen Çamlık tüneli ise çoğunlukla C2 kaza ve destek sistemi ile 6 aşamalı olarak kazılmaktadır. Ayrıca; Riva tüneli iç kaplama betonu imalatında çelik tel (fiber) katkılı beton uygulaması başarıyla gerçekleştirelmektedir.

Parçalı kaza yöntemi ile açılan geniş açıklıklı tünel niteliğindeki Riva ve Çamlık tüneleri, Türkiye’de özellikle son yıllarda gerçekleştiriliren yüksek standartlı karayolu yapım çalışmalarını ile birlikte hızla gelişen karayolu tunelcililiğinde yeni ve önemli bir kilometre taşı olup, uluslararası ölçekte ölcükleri büyük mühendislik çalışmaları literatüründe de üst surlarda yer alacaktır.

Anahtar Kelimeler: Geniş Açıklıklı Tünel, Karayolu, NATM, Tünel
1. Giriş


Kuzey Marmara Otoyolu, Odayeri – Paşaköy güzergahının Asya yakasında Km: 0+000 – 12+733 arasında Çamlık-Reşadiye bağlantı yolunu yer almaktadır. Çamlık – Reşadiye arasında 6 adet viyadük, 10 adet üst geçit köprüsü, 10 adet alt geçit köprüsü ve 1 adet tünel yer almaktadır. Çamlık – Reşadiye bağlantı yolunu üzerinden yer alan Çamlık tünelleri kuzey ve güney olmak üzere 2 tüpten oluşmaktadır. Kuzey tüp Km: 3+715 – 4+267 aralığında olup uzunluğu 552 m, güney tüp ise Km: 3+728 – 4+379 aralığında 651 m uzunluğundadır. (Şekil 1.)

Şekil 1. Çamlık tünelinin proje güzergahı üzerindeki lokasyonu.

Tünelin yönü güneybatıdan kuzeydoğuya doğrudur. Tünelin boyuna yol eğimi %1,7 (giriş ve çıkış arasındaki kot farkı 12m), yatay kurp yarıçapı ise 1.350 m’dir.
Şekil 2. Çamlık tüneli proje tip kesiti.

Her bir tüp 4 şeritli olacak olan tünelin kazi genişliği 21,80 m ve yatay gabaşları 15,50 m'dir. Düseyde ise tünelin kazi yüksekliği 13,00 m, nihai kaplama sonrası maksimum yükseklik 8,45 m ve düsey gabaşları 5,00 m olacaktır. Çamlık tüneli üzerindeki örtü kalınlığı ise en fazla 60 m seviyelerine ulaşmaktadır. Tünel örtü kalınlığı, güneşi tüp giriş-çıkış portallerinde yaklaşık 10 m ve kuzey tüp giriş portalinde 10 m, çıkış portalinde ise yaklaşık 12 m dolyanadır.

Şekil 3. Çamlık Tüneli’nin proje içerisindeki detay yerleşim planı.

2. Tünel Güzergahının Jeolojisi ve Depremelliği

Yapılan çalışmalar sonucunda; tünel güzergahının genel jeolojisi ile hidrojeolojisi özetlenmiş, birimlerin mühendislik jeolojisi özellikleri açıklandan yapılan homojen bölgelendirmeye göre kaya kültüleri sınıflamaları yapılmıştır. Laboratuvar deneyleri ve ampirik hesaplar sonucunda, belirlenen kritik kesimlerin stabilite analizlerinde kullanılacak parametreler kararlaştırılmıştır. Kaya kültüleri sınıflamalarına ve tünel kazi kesitine uygun şekilde kullanılacak destek sistemlerine karar verilmiştir.

Tünel güzergahında 3 farklı jeolojik formasyon yer almaktadır. Jeolojik olarak tabanda Alt-Orta Ordovisyen yaşlı, başlica arkoz bileşimindeki kıırımlı kayalardan oluşan Kurtköy Formasyonu; üzerinde yine aynı yaşlı, büyük bölümüyle kuvarsıtlar (kuvarsarenit) oluşan Aydos Formasyonu ve Üst Ordovisiyen-Alt
Silüriyen yaşlı, ince tabakalı ve laminalı silttaşı-şeyl ile ince-orta tabakalı kumtaşı ardalanmasından oluşan Yayalar Formasyonu’nun Gözdağ Üyesi bulunmaktadır.

Tünel kilometre artişına göre Gözdağ Üyesi’nin tümüyle ayrışmış (zeminesmiş) kesimlerinden başlayıp, Aydos (Kuvarsit) - Kurtköy Formasyonu’ndan (Arkoz) devam edip, Kurtköy Formasyonu ile son bulunmaktadır.

Asya yakasındaki Kuzey Marmara Otoyolu 1. ve 2. derece deprem bölgeleri içerisinde yer almaktadır. Türkiye deprem bölgeleri haritasına göre Çamlık Tüneli 2. derece deprem bölgesinde bulunmaktadır. 2. Derece deprem bölgesi: beklenen ivme değeri 0,40 g ile 0,30 g arasında ve \( A_0 = 0.3 \) g’dir.

Şekil 4. Çamlık Tüneli’nin İstanbul ilı deprem bölgeleri haritası üzerine işlenmiş durumu.

3. Zemin Araştırmaları Özeti ve Kaya Kütesi Sınıflandırmaları

Jeolojik birimlerin mühendislik özelliklerini, yeraltı suyu durumunu ve ortamın kaya kalitesini saptamak amacıyla Çamlık Tüneli güzergahında 12 adet sondaj yapılmıştır. Karotlu olarak gerçekleştirilen sondajların derinlikleri 30 – 85 m arasında olup toplam sondaj boyu 641 m’dir. (Şekil 5.)

Tünel giriş portali yakınında bulunan su deposundaki yarmadan ve JCB ile açılan 9 adet gözlem çukurları yapılmıştır. Her çukurunun derinliği, genişliği ve yüksekliği ölçülerek kayan kayaç tabakaların doğrultuları D-B, KD-GB ve eğim yönleri G-GD 33-60° olduğu anlaşılmıştır. Photograph of Mosque in Istanbul showing the structure and surrounding area.

Kayaçların geçirmililiğinin saptanması amacıyla sondaj kuyuları içerisinde yaklaşık tünel seviyesinde 20 adet BST – basınçlı su testi yapılmıştır. Bu test, kayaçların inşaat potansiyeline ve inşaat potansiyelini değerlendiren, Lugeon yöntemi kullanılarak belirlenmiştir. Deney sonuçlarına göre; Lugeon birimleri 0,5–1,5 olarak tespit edilmiş olup, buna göre jeolojik birimlerin geçirilmiş – az geçirilmiş niteliktedir.

Açılan sondaj kuyularının yanı sıra, tünel güzergahında yer alan jeolojik birimlerin sismik hızlarını (P ve S) ve kalınlıklarını belirleyebilmek amacıyla 1 profil boyunca sismik etüt (kirişma (P dalgası) ve aktif kaynak yüzey dalgası) yapılmıştır.

Saha gözlemleri, sondaj ve jeofizik çalışmalar, yerinde (SPT, presiyometre ve BST) ve laboratuvara (nokta yüklemeye, tek eksenli basınç, üç eksenli basınç, endirekt çekme vb.) gerçekleştirdiğimiz deneylere ait sonuçlar birlikte değerlendirilerek tünel jeolojik modeli oluşturulmuştur.
Şekil 5. Çamlık Tüneli sondaj lokasyon planı.


Kaya kültüsi sınıflama sistemleri genellikle kayanın sahip olduğu süreksizlik özelliklerini, kaya dayanımını, su durumunu, aşınma durumunu ve tünel çevresinde yerleşen yer alan gerilme durumunu kullanarak kaya kalitesini belirlemeye çalışan yöntemlerdir. Ancak ülkemizde en çok RQD – Deere, Q – Barton ve RMR – Bieniawski sınıflamaları tünel inşaatları sırasında tercih edilmektedir. Çamlık Tüneli için kaya kalite sınıflamaları RQD, Q ve RMR yöntemleri kullanılarak yapılmıştır.

Yeni Avusturya Tünel Açma Yöntemine (NATM) göre kaya destekleme sınıfı da kaya kalitelerine bağlı olarak belirlenebilmektedir.

**Çizelge 1. Çamlık Tüneli kaya kültüsi sınıflandırmaları ve homojen bölgelendirme.**

<table>
<thead>
<tr>
<th>Kesim No</th>
<th>Kilometre Aralığı</th>
<th>Kesim Uzunluğu (m)</th>
<th>Kesim Özelliği</th>
<th>Litoloji</th>
<th>RQD</th>
<th>Q</th>
<th>RMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kuzey</td>
<td>3+715-3+735</td>
<td>20</td>
<td>Giriş Portali</td>
<td>Tamamen ayr. Kumtaşı-Silttaşı</td>
<td>14</td>
<td>0,029</td>
</tr>
<tr>
<td>Güney</td>
<td>3+728-3+760</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Kuzey</td>
<td>3+735-3+850</td>
<td>115</td>
<td>Geçiş Zonu / Fay Zonu</td>
<td>Kumtaşı-Silttaşı</td>
<td>5</td>
<td>0,293</td>
</tr>
<tr>
<td>Güney</td>
<td>3+760-3+870</td>
<td>110</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Kuzey</td>
<td>3+850-4+220</td>
<td>370</td>
<td>Derin Tünel</td>
<td>Kuvarsit</td>
<td>5</td>
<td>0,147</td>
</tr>
<tr>
<td>Güney</td>
<td>3+870-4+180</td>
<td>310</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Kuzey</td>
<td>4+220-4+267</td>
<td>47</td>
<td>Çıkış Portali</td>
<td>Arkoz</td>
<td>17</td>
<td>0,499</td>
</tr>
<tr>
<td>Güney</td>
<td>4+180-4+379</td>
<td>199</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. Kazı aşamaları ve destek sistemleri

Kaya kalite sınıflamalarına bağlı olarak yapılan NATM sınıflamasında kaya destek sınıfları B3, C2, C3 ve C4 olarak belirlenmiştir. Tünel kazısı NATM metodu ile 6 aşamada yapılmaktadır. Aşamalar geçiş mesafeleri ve kazi kesit alanları Şekil 6.’da gösterilmiştir;

I. Aşama (52,48 m²): 50 metre ilerledikten sonra II. Aşama (52,48 m²) kazısı,
II. Aşama: 50 metre ilerledikten sonra III. ve IV. Aşama (32,57 m²) kazıları,
I. ve II. Aşama kazıları 150-200 m ilerledikten sonra V. Aşama (38,16 m²) kazısı
V. Aşama kazısı 30 m ilerledikten sonra VI. Aşama (18,39 m²) kazısına başlanmaktadır. Toplam kazı alanı 226,65 m²'dir.

Şekil 6. Çamlık Tüneli kazı aşamaları.

<table>
<thead>
<tr>
<th>Kesim No</th>
<th>Kilometre Aralığı</th>
<th>Kesim Özelliği</th>
<th>Litoloji</th>
<th>Q</th>
<th>RMR</th>
<th>Destek Sınıfı</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kuzey 3+715-3+735</td>
<td>Giriş Portali</td>
<td>Tamamen ayr. Kumaş-Silttaşı</td>
<td>0,029</td>
<td>12 (çok zayıf kaya)</td>
<td>C3 “Çok baskı” kaya</td>
</tr>
<tr>
<td></td>
<td>Güney 3+728-3+760</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>“Akıcı” kaya</td>
</tr>
<tr>
<td>2</td>
<td>Kuzey 3+735-3+850</td>
<td>Geçiş Zonu / Fay Zonu</td>
<td>Kumaş-Silttaşı</td>
<td>0,293</td>
<td>14 (çok zayıf kaya)</td>
<td>C3 “Çok baskı” kaya</td>
</tr>
<tr>
<td></td>
<td>Güney 3+760-3+870</td>
<td></td>
<td>Fay Zonu</td>
<td>0,031</td>
<td>12 (çok zayıf kaya)</td>
<td>“Çok baskı” kaya</td>
</tr>
<tr>
<td>3</td>
<td>Kuzey 3+850-4+220</td>
<td>Derin Tünel</td>
<td>Kuvarsit</td>
<td>0,147</td>
<td>18 (çok zayıf kaya)</td>
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<tr>
<td></td>
<td>Güney 3+870-4+180</td>
<td></td>
<td>Arkoz</td>
<td>0,499</td>
<td>42 (orta kaya)</td>
<td>“Baskılı” kaya</td>
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<tr>
<td>4</td>
<td>Kuzey 4+220-4+267</td>
<td>Çıkış Portali</td>
<td>Arkoz</td>
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<td>28 (zayıf kaya)</td>
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<td></td>
<td>Güney 4+180-4+379</td>
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</tbody>
</table>
### Çizelge 3. Çamlık Tüneli için önerilen destek elemanları.

<table>
<thead>
<tr>
<th>Destekleme Tipi</th>
<th>B3</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
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</thead>
<tbody>
<tr>
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<tr>
<td>Geçici</td>
<td>-</td>
<td>1,5”</td>
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<td>4”</td>
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<tr>
<td><strong>Kesim</strong></td>
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<td>-</td>
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<td><strong>Miktar</strong></td>
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<tr>
<td>Kalıcı</td>
<td>-</td>
<td>9 m</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

| **Püskürtme**   |    |    |    |    |
| Tip             | C25/30 | C25/30 | C25/30 | C25/30 |
| **Beton**       |    |    |    |    |
| Tip             | Q188/188 | Q221/221 | Q188/188 | Q377/377 |
| **Çelik**       |    |    |    |    |
| Tip             | Ø32x1/ Ø26x2 | Ø32x1/ Ø26x2 | Ø32x1/ Ø26x2 | Ø32x1/ Ø26x2 |

| **Kaya**        |    |    |    |    |
| Bulonu          |    |    |    |    |
| Tip             | PG | PG | IBO | PG |
| **Radyal**      |    |    |    |    |
| Adımı           | 1,5 m | 1,5 m | 1 m | 1 m |
| **İlerleme**    |    |    |    |    |
| Adımı           | 1,5 m | 1,5 m | 1,5 m | 1,5 m |

* Gerektiği yerde IBO bulon kullanılacaktır.
Şekil 7. Çamlık Tuneli örnek destekleme (C2 sınıfı) tip kesiti.

5. Sonuç ve Değerlendirmeler

Kuzey Marmara Otoyolu, Odayeri – Paşaköy güzergahının Asya yakasında Km: 0+000 – 12+733 arasında Çamlık – Reşadiye bağlantılı yolu yer almaktadır. Çamlık – Reşadiye arasındaki 6 adet viyadük, 10 adet üst geçit köprüsü, 10 adet alt geçit köprüsü ve 1 adet tünel yer almaktadır. Çamlık – Reşadiye bağlantı yolu üzerinde yer alan Çamlık tuneli kuzey ve güney olmak üzere 2 tüpten oluşmaktadır. Kuzey tüp Km: 3+715 – 3+267 aralığında olup uzunluğu 552m, güney tüp ise Km: 3+728 – 4+379 aralığında 651 m uzunluğundadır.

Her bir tüpü 4 şeritli olarak olan tünelin kazı genişliği 21,80 m ve yatay gabari 15,50 m’dir. Düşeyde ise tünelin kazı yüksekliği 13,00 m, nihai kaplama sonrası maksimum yükseklik 8,45 m ve düşey gabari 5,00 m olacaktır. Çamlık tuneli üzerindeki örtü kalınlığı ise en fazla 60 m seviyelerine ulaşmaktadır. Tunel örtü kalınlığı, güney tüp giriş-çıkış portallerinde yaklaşık 10 m ve kuzey tüp giriş portalinde 10 m, çıkış portalinde ise yaklaşık 12 m dolayındadır.


Çamlık Tuneli’nin bulunduğu kesimde kaya türü olarak kumaşta (arkoz), kuvarsit ve mikalı kumaş-silttaş birimlerin tamamen ayrışmış (şarkın niteliğindek) kesimleri görülmemiştir. Mor renkli kumaşta (arkoz) ve kirli beyaz, pembensi, açık beş renkli kuvarsit birimleri genel olarak orta sağlam-sağlam dayanımlı, çok sık çatlaklı, taze-az ayrımsız niteliktedir. Sürekzilik yüzeyi dalgalı-pürüzlü olmakla birlikte, 1 m’ye düşen sürekzilik sayısı 1 adettir. Sürekzilik devamlılığı 1-10 m’dir. Sürekzilik aralığı 20-600 mm aralığındadır. Sürekzilik açıklığı 20-60 mm’dir. Dolgu malzemesi kum-silt yer yer kil malzemeleridir.

Kaya kalite sınıflamalarına bağlı olarak yapılan NATM sınıflamasında kaya destek sınıfları B3, C2, C3 ve C4 olarak belirlenmiş olup tünel kazısı 6 aşamada yapılmaktadır. 
6. Kaynaklar


PAPER TITLE
EDİRNE İL MERKEZİNDE YER ALAN TARİHİ KÖPRÜLERİN STRÜKTÜR SİSTEMLERİİNİN İNCELENMESİ VE TARİHİ YAPIM TEKNOLOJİSİNİN BELİRLENMESİ

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KEYWORDS:
Strüktür Sistemler, restorasyon, tarihi köprüler

ABSTRACT:
Edirne İl Merkezi’nde yer alan, korunması gerekli taşınmaz kültür varlığı olarak tescilli Tunca, Meriç, Gazimihal, Yalnızgöz, Bayezid, Sarachoane, Kanuni ve Fatih köprülerin de uygulanan geleneksel yapım tekniği ve strüktür sistemlerinin belirlenmesi, geleneksel yapı malzemelerinin özelliklerinin tespit edilmesi için köprü ayaklarında ve temel sistemlerinde çalışmalar yapılmıştır.


Tunca Köprüsü’nde 5 adet, Meriç Köprüsü’nde 9 adet, Gazimihal Köprüsü’nde 4 adet, Bayezid, Sarachoane, Kanuni Köprülerinde 2’şer, Fatih ve Yalnızgöz Köprülerinde 1’er adet rotari yöntemle ve su dolaşımlı sondaj yapıtların karot alınmıştır. Sondaj esnasında SPT deneyleri, laboratuvar ortamında ise alınan karotlarda sınıflama (indeks özellik) deneyleri, köprüye ait harç numunelerinde asit testi, elek analizi, kimyasal spot analizi ve kalsinasyon analizi yapılmıştır.

Sonuç olarak sondaj ve malzeme analizleri sonucunda elde edilen veriler, köprülerin yapım tekniklerinin anlaşılabilmesi ve aynı dönem köprülerine yapılacak müdahale kararlarında yol göstermesi açısından önem arz etmektedir.
Edirne İl Merkezinde Yer Alan Tarihi Köprülerin Strüktür Sistemlerinin İncelenmesi Ve Tarihi Yapım Teknolojisinin Belirlenmesi

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1 GİRİŞ


Tarihi köprü üzerinde rotari yöntemi ve su dolaşımlı sondaj yapılarak karot alınmıştır. Tunca Köprüsü’nde 5 adet, Meriç Köprüsü’nde 9 adet, Gazimihal Köprüsü’nde 4 adet, Bayezid, Saraçhane, Kanuni Köprülerinde 2’şer, Fatih ve Yalnızgöz Köprülerinde 1’er adet karot numunesi alınmıştır. Sondaj esnasında SPT deneyleri, laboratuvar ortamında ise alınan karotlarda sınıflama (indeks özellik) deneyleri, köprüye ait harç numunelerinde asit testi, elek analizi, kimyasal spot analizi ve kalsinasyon analizi yapılmıştır. Köprü temellerinin birçoğunda yapılan incelemelerde, temellerin altında ahşap izgara ve kazık sistemleri kullanıldığı anlaşılmaktadır. Taş köprülerin yapıldığı bölgelerin genel olarak düz olması ve taşıma gücü zayıf zeminlerden oluşması dolayısıyla temeller ahşap kazıklar veya 2-3 sıradan oluşan ahşap izgaralar üzerine inşa edilmişlerdir. (bkz. Figür 1) Sondaj ve malzeme analizlerinden elde edilen veriler, köprülerin yapım tekniklerinin anlaşılabilmesi ve aynı dönemdeki köprülerin yapılış çağında yani Tarih 1500 sonrasında yapılabilir köprülerin ne kadar kullanılmış olup olmadığı araştırılmalıdır.

Bu çalışmadı; Edirne İli dahilinde bulunan Tarihi Köprülerde uygulanan geleneksel yapım teknikleri ve strüktür sistemlerinin belirlenmesi, geleneksel yapının temellerinin tespit edilmesi için köprü ayaklarında ve temel sistemlerinde yapılan çalışmaların değerlendirilmesi, köprü temellerinin hangi şekilde yapılmış, fiziksel ve kimyasal analiz de deney sonuçları ile harç numuneleri analizleri hakkında kısa bilgi verilmiştir.

2 STRÜKTÜR SİSTEMLER VE TARIHİ YAPIM TEKNOLOJİSİNİN BELİRLENMESİ

Yapılışda çalışma sadece yolların ve atların geçişini sağlamak için planlanmış, oysa günümüzde taşıt trafiğini de geçirmek zorunda bırakılan tarihi köprülerinizi emniyetli bir geçiş imkan vermesi için önemsikle stabil olmaları gerekmektedir.

Bundan nedenle; tarihi köprülerin onarımı esnasında kullanılan malzemelerle ilişkili olarak, yapılacak onarımarda stabiliteyi bozan etkenlerin ortadan kaldırılması ve kullanılan malzemelerin durumu saptanması, malzemelerin de buna göre seçilmiş hale getirilmesi gerekmektedir. Tarihi köprü restorasyon teknikinde esas amaç olan en az müdahale yani sağlamlaştırma pekine, köprüünün tarihi belge ve estetik değeri korunarak orijinaline en uygun şekilde ve gereksiz eklenlendirmeler arındırılarak onarının gerçekleştirilmesi gerekmektedir.

Bu süreçte 3 T şeklinde adlandırılan, “Tespit, Teşhis, Tedavi” aşamaları, durum saptamasının tam ve doğru bir şekilde yapılabildi ve gerçekleştirerek onarım için müdahale yöntemlerinin belirlenmesi ve uygulanabilmesi açısından büyük önem taşmaktadır.
2.1. KÖPRÜ ELAMANLARI VE YAPIM TEKNİĞİ

Edirne İlinde bulunan tarihi köprülerin tamamı diyebileceğimiz oranda Osmanlı Döneminde yapılmış olup, strüktür sistemlerini incelediğimizde aşağıda açıklanan hususlar tespit edilmiştir. (KGM Yayın No:268 2009).


Tunca Köprüsü ayaklarında derinlikleri 6,34 m ile 24,00 m arasında değişen 6 adet sondaj yapılmıştır. Sondaj loglarına göre temellerin alüvyon zemin üzerine oturan, alt kotları değişikken yüzeysel temeller olduğu, temel altlarında ahşap zgara ve kazık sistemi bulunduğunu anlaşılmıştır. Köprü temelleri altında bulunan kum tabakasının kalınlığı ortalamalaraksız 3,0m ile 6,0 m arasında değiştiği tespit edilmiştir. Köprü altında bulunan kum tabakasının kalınlığı SPTN değerleri 50’nin üzerinde olup, köprü dışındaki zeminde SPTN değerleri 30 civarında bulunmaktadır. Siltli kil numunesi üzerinde yapılan konsolidasyon deneyinde, ön konsolidasyon basıncı 500 kpa, OCR değeri 4,5 dir.(ZTM 2005)

Tarihi Meriç Köprüsü ayaklarının oturduğu zemini araştırmak için köprü üzerinde derinlikleri 6,0 m ile 25,5 m arasında değişen 9 adet ve köprü yakınındaki zemin üzerinde de 1 adet sondaj yapılmıştır. (Figür 1) Sondajdan alınan numunelerin üstü İstanbul Kültür Üniversitesi Geoteknik Laboratuvarında yıkmalı ele analizi deneyi, tek nokta yöntemi ile kıvam limiti tayini (ASTM 4318-93), sınıflandırma deneyleri ve konsolidasyon deneyi yapılmıştır.

Yapılan sondajlardan, tarihi köprüünkü, Meriç nehri'nin kumlu zeminine inşa edildiği, temel güvenliği için de ahşap kazıkların kullanıldığı belirlenmiştir. Köprü temelleri altında bulunan kum tabakasının kalınlığı ortalamalaraksız 7,50 m olarak tespit edilmiştir. Köprü altında bulunan kum tabakasının kalınlığı SPTN değerleri 50’nin üzerinde olup, köprü dışındaki zeminde SPTN değerleri 30 civarında bulunmaktadır. Siltli kil numunesi üzerinde yapılan konsolidasyon deneyinde, ön konsolidasyon basıncı 280 kpa ölçülmüş olup, OCR değeri 4,5 dir. (IKÜ 2006)


**Tunca Köprüsü:** 136,30 m uzunluğunda, genişliği ise 6,90 m olan köprünün mimarı Sedefkar Mehmet Ağa’dır. III. Mehmet zamanında defterdarlık yapmış olan Ekmekcizade Ahmet Paşa tarafından H 1016 – 1024 (M 1607 – 1615) tarihleri arasında inşa edilmiştir. Köprü, iki yanda ikişer boşaltma gözüyle beraber toplam 12 gözli taş yıva bir köprüdür. Boşaltma gözleri tek merkezli dairesel kemer, diğer gözler basık sivri kemer formundadır. 20. yüzyıl başlarında yıkılan 2 kemeri yeniden inşa edilmiş olup bu inşa işlemlerini sırasında orijinal malzeme ve yapı şekli ile modern yardımcı aletler kullanılmıştır. Söz konusu kemelerin yeniden inşası kemer köprülerin yapım yöntemlerinin araştırılması konusunda yol gösterici olmuştur (Figür 2),(Teknik Rapor 1 2008)

![Figür 2 Tunca köprüsü kemerlerin yeniden inşası çalışmaları](image1.jpg)

**Meriç Köprüsü:** Üçüncü dönem (1842) Osmanlı eserlerinden olan ve Sultan Abdülmeclit döneminde açılan, Genç Osmanlı dönemi olan köprü, 222,30 m uzunluğundadır. 12 Adet basık sivri kemer ve ortasından her yana boyuna eğimli Tunca Köprüsüne benzemekle beraber Meriç Nehrinin her iki yakasının kot farkından dolayı tam bir simetriden bahsedilemez. (Figür 3),(Teknik Rapor 2 2008)

![Figür 3 Meriç Köprüsü](image2.jpg)

**Kanuni Köprüsü:** 1553-1554 yıllarında Mimar Sinan tarafından yapılmıştır. 67,3 metre uzunluğunda olup, açıklıkları 9,75 metre, köprü yolu genişliği 5,35 metredir. Dört gözlüdür. Düzgün köşe planlı, başlık kısmını piramit şeklindedir. Köprü gözleri orta ayağın sağ ve solunda yer alır. Ayaklarda boşaltma gözleri yoktur. (Teknik Rapor 3 2008)

**Gazimihal Köprüsü:** Uzunluğu 184,18 m, genişliği ise 5,90 m olan 16 açıklıklı, Romalılar zamanında mevcut olan köprü, Michael Paleologos (1261-1282) devrinde de kullanılmıştır. Edirne’nin Osmanlılar tarafından 1362 yılında fethedilmişesinden sonra onarılan bu köprüye akıncı komutanını adı olan Gazimihal ismi verilmiştir. Köprü, Sultan II Hamid zamanında da (1900-1903) esaslı bir onarım görmüştür. Bu nedenle de bir adı Hamidiye köprüsüdür. Köprü 16 adet basık dairesel (Sepet Kulpu) şeklinde benzer çaptaki kemer yapısı ile Osmanlı dönemi Edirne Köprülerinden farklılaşmaktadır. (Figür 4),(Teknik Rapor 4 2008)
Yalnızgöz Köprüsü: 1570 yılında II. Selim adına Tunca Nehri’nin kollarından birinin üzerine yaptırılmıştır. 6 gözlü olmasına rağmen gözlerden biri farklı bir şekilde olduğu için bu isimle anılmaktadır. 92,18 m uzunluğunda ve 6,0 m genişliğinde olan köprü, Sivri kemer yapısı ile Osmanlı döneminde yapılan köprülere benzerlik gösterse de gerek kemerlerin asimetrik dizilişi gerekse de ortasında bulunan rıhtım yapıları ve kendine has siluetiyle taş kemer köprüler arasında benzersiz bir yere sahiptir. (Figür 5),(Teknik Rapor 5 2008)

Bayezid Köprüsü: II. Beyazıt zamanında (1488 yılında) Mimar Hayrettin tarafından yapılan köprü 6 gözlü ve 115,82 m uzunluğunda, 5.70 m genişliğindekdir. Asimetrik olarak dizilmiş 6 büyük ve 1 küçük sivri kemerden oluşmaktadır. (Figür 6),(Teknik Rapor 6 2008)
Saraçhane Köprüsü: Edirne-Sırpsındığı yolu, Tunca nehri üzerinde 1451 yılında yapılmış olan köprüün boyu 150 m, genişliği ise 5,60 m'dir. 11 Adet farklı çaptaki basık sivri kemerden oluşmaktadır. Köprü hem kemer dizilişi hem de siluet bakımından asimetrik. (Figür 7),(Teknik Rapor 7 2008)

Fatih Köprüsü: 1452 yılında Fatih Sultan Mehmet tarafından yaptırılan köprüün boyu 40,75m, genişliği ise 4,56m'dir. 3 gözlü hafif sivri kemerden oluşmaktadır. (Figür 8)

Korkuluk ve Kornişler: Osmanlı dönemi köprülerinde gelişen ve en olgun şeklini bulan korkuluklar, dıştan tempan duvar üzerinde köprü doşeme seviyesini işaretleyen, kornişli bir geçiş düzeni ile belirlenmektedir.

Malzeme: Kullanılan ana malzeme taştır. Taş malzeme kullanılmasının nedeni bölgesel bir geleneğin etkisi olarak yorumlanabilir. Bağlayıcı olarak iyi cins kireç harcı ile birlikte horasan harcı kullanılmış, ayrıca kurşunlu kenet ve zıvana ile bağlanıtları yapılmıştır.

2.2. TARİHİ KÖPRÜLERDEN ALINAN ORJİNAL HARÇ NUMUNELERİNİN ANALİZLERİ

Harç analizi sonuçlarına göre; agregaların büyük çoğunluğunun özel kullanılmış karasal kökenli, beyaz ve opak kuartz agregadan oluşan, küçük boyutta bol mikası olan, ayrıca iri boyutta dolgu malzemesi olarak kullanılan agregaların bir kısının kireç taşı gibi bir kısmından oluştuğu tespit edilmiştir. Öğün harçların analizleri sonucunda; içeriğinde taşı veya tuğla kırığın içeren kireç esaslı harçların kullanıldığı, basınç dayanıklarının ise 4-8 Mpa arasında değiştiği tespit edilmiştir. Harçların uzun yıllar su ve farklı içerikteki karışımlara maruz kaldığı düşünülmüş ve halen yüksek dayanımı olması, kullanılan bağlayıcı çöken çok kaliteli ve su dayanımı yüksek hidrolik özellikleri bir bağlayıcı olduğu görülmüştür.
Kullanılan agregalar, yöreye özel ocaklardan çıkarılan taşların pirinci ve tozunun kullanılmış olduğunu göstermektedir. (H. Sert 2013) Sadece Kanuni ve Fatih Köprüleri’ne ait harçlar, horasani harç olup, bağlayıcı agrega oranı ½, 1/1,5 dir. Diğer köprülerde 1 bağlayıcı, 3 agrega oranında harç kullanıldığı, Tunca, Meriç ve Bayezid Köprüsü harcında az miktarda katkı olarak kireç taşı agrega rastlanmıştır. Diğer köprülerde özel katı kumu ve bir miktar kumaş ve şişik agregayı ilavelidir. Harçlarda, yöreye özel maden ocaklardan çıkarılan kireç taşı agrega, kara harç kumu, bir miktar kumaş ve şişik agregayı kullanılmıştır. 

Tablo 1 Tarihi Köprülerden Alınan Orjinal Harçlar Üzerinde Yapılan Kalsinasyon ve Kimyasal Spot Test Analizleri

<table>
<thead>
<tr>
<th>KÖPRÜ ADI</th>
<th>GÖRÜNÜŞ</th>
<th>NEM MIKTARI % (105°C, 24 Saat)</th>
<th>ORGANİK MADDE MIKTARI % (550°C, 6 Saat)</th>
<th>CaCo3 MIKTARI (g/kg)</th>
<th>ASİT KAYBI % (%10’lu HCl İle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TUNCA</td>
<td>Beyaz ve opak kuarz agrega, Kullanılan agregaın bir kısmı kireç taşı bir kısmı volkanik taşı.</td>
<td>0,61</td>
<td>1,65</td>
<td>87,48</td>
<td>36,57</td>
</tr>
<tr>
<td>MERİÇ</td>
<td>Beyaz ve opak kuarz kumu, %5 civarında karşılık agrega, 250 ve 125 mikron boylarında kırılgan, Kullanılan agregaın bir kısmı kireç taşı bir kısmı volkanik taşı.</td>
<td>5,73</td>
<td>10,17</td>
<td>22,75</td>
<td>50,3</td>
</tr>
<tr>
<td>BAYAZIT</td>
<td>Büyük bölümü Beyaz kuarz ve daha az miktarla opak kuarz agrega, Max tane boyutu 7-8mm. Hidrolık özellikleri baglayıcı kullanılanı.</td>
<td>6,06</td>
<td>10,86</td>
<td>15,46</td>
<td>33,66</td>
</tr>
<tr>
<td>ALNIZGÖZ</td>
<td>%60 opak, %40 beyaz kuarz olan karışım. Hidrolık veya puzzolanik özellikli katkı kullanılanı. Baglayıcı agrega oranı 1/3.</td>
<td>4,36</td>
<td>6,42</td>
<td>12,31</td>
<td>23,75</td>
</tr>
<tr>
<td>GAZİMİHAL</td>
<td>Büyük bölümü Beyaz kuarz ve daha az miktarla opak kuarz agrega, iri boyutlu agrega fazla, kireç taşı ihtiyaç eden.</td>
<td>4,78</td>
<td>5,2</td>
<td>9,11</td>
<td>21,82</td>
</tr>
<tr>
<td>SARAÇHANE</td>
<td>Tüm malzemelerin %35-40 kuarz, geri kalani tuğla kriniği ve tozudur. 1mm elek üstünde kalan agreganın max dane cap 3-4mm dir. Baglayıcı agrega oranı 1/1,5, dayanımı iyi,</td>
<td>4,38</td>
<td>6,22</td>
<td>14,83</td>
<td>30,11</td>
</tr>
<tr>
<td>KANUNİ</td>
<td>Tüm malzemelerin %35-40 kuarz, geri kalani tuğla kriniği ve tozudur. 1mm elek üstünde kalan agreganın max dane cap 3-4mm dir. Baglayıcı agrega oranı 1/1,5, dayanımı iyi,</td>
<td>30,85</td>
<td>7,88</td>
<td>37,88</td>
<td>82,86</td>
</tr>
<tr>
<td>FATİH</td>
<td>Tüm malzemelerin %25-30 tuğla kriniği ve tozu,%65-70’tür kuarz agregasıdır. 1mm elek üstünde kalan agreganın max d. cap 8mm dir. 125mikron altı toz boyutu fazladır. Kireç / agrega oranı ½ civardadır.</td>
<td>7,19</td>
<td>9,29</td>
<td>29,7</td>
<td>73,36</td>
</tr>
</tbody>
</table>
### Tablo 2 Orjinal Harçlar Üzerinde Yapılan Test Analizleri Ve Yeni Hazırlanacak Harç Karışım Oranları

<table>
<thead>
<tr>
<th>KÖPRÜ ADI</th>
<th>GÖRÜNÜŞ</th>
<th>KİREÇ BAĞLAYICI</th>
<th>AGREGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TUNCA</td>
<td>Beyaz ve opak kuartz agregası, Kullanılan agregaların bir kısmı kireç taşı, bir kısmı volkanik taş.</td>
<td>%25 Hidrolık Özellikli Kireç</td>
<td>%75 (%10 kireçtaşı agregası, geri kalani kuartz aggregasi, opak ve beyaz renkli kuartz. İlaveten dolgu malzemesi olarak 8mm-2cm boyutları arasında değişim gösteren toplaman %10’u kadar agrega.)</td>
</tr>
<tr>
<td>MERİÇ</td>
<td>Beyaz ve opak kuartz kumu, %5 civarında karışık agregası, 250 ve 125 mikron boyutlarında cürf, Kullanılan agregaların bir kısmı kireç taşı, bir kısmı volkanik taş.</td>
<td>%25 Hidrolık Özellikli Kireç</td>
<td>%75 (%10 kireçtaşı agregası, geri kalani kuartz aggregasi, opak ve beyaz renkli kuartz. İlaveten dolgu malzemesi olarak 8mm-2cm boyutları arasında değişim gösteren toplaman %10’u kadar agrega.)</td>
</tr>
<tr>
<td>BAYAZIT</td>
<td>Büyük bölümü Beyaz kuartz ve daha az miktarda opak kuartz aggregası, Max tane boyutu 7-8mm. Hidrolık özellikleri bağlıcısı kullanılmış</td>
<td>%25 Hidrolık Özellikli Kireç</td>
<td>%75 (%10 kireçtaşı agregası, geri kalani kuartz aggregasi, opak ve beyaz renkli kuartz. İlaveten dolgu malzemesi olarak 8mm-2cm boyutları arasında değişim gösteren toplaman %10’u kadar agrega.)</td>
</tr>
<tr>
<td>YALNİZGÖZ</td>
<td>%60 opak, %40 beyaz kuartz olan karışım. Hidrolık veya puzzolanik özellikleri katkı kullanılarak. Bağlayıcı agreganın oranı 1/3.</td>
<td>%25 Hidrolık Özellikli Kireç</td>
<td>%75 Kuartz (beyaz renkli ve opak) agregası.</td>
</tr>
<tr>
<td>GAZİMİHAL</td>
<td>Büyük bölümü Beyaz kuartz ve daha az miktarda opak kuartz agregası, iri boyutlu aggregasi fazla, kireç taşı ihitva eden,</td>
<td>%25 Hidrolık Özellikli Kireç</td>
<td>%75 Kuartz (beyaz renkli ve opak) agregası.</td>
</tr>
<tr>
<td>SARÂÇHANE</td>
<td>Tüm malzemenin %35-40 kuartz, geri kalani tuğla kırığı ve tozudur. 1mm elek üstündeki kalan agreganın max dane/cgi: 3-4mm dir. Bağlayıcı agreganın oranı 1/1,5, dayanımı iyi,</td>
<td>%30 (Hidrolık kireç ya da iyi kalitede sendürilmüş ve uzun süre bekletilmiş kireç)</td>
<td>%70 Kuartz aggrega, 6mm elek alt, içine %3 civarında puzzolanik karakterli kil veya tuf tozu katılmaktadır. Ayrıca toplam agreganın %10 kadar 6mm-1,5cm aralığında silika kumu ilavesi yapılmaldır.</td>
</tr>
<tr>
<td>KANUNİ</td>
<td>Tüm malzemenin %35-40 kuartz, geri kalani tuğla kırığı ve tozudur. 1mm elek üstündeki kalan agreganın max dane/cgi: 3-4mm dir. Bağlayıcı agreganın oranı 1/1,5, dayanımı iyi,</td>
<td>%30 Hidrolık Özellikli Kireç</td>
<td>%70 (%25 kireçtaşı, %25 tuğla kırığı, geri kalani kuartz aggregasi, 5mm elek alt ve kırışımın %10-15’i kadar 8mm-1cm arası kuartz aggregasi ve tuğla kırığı ilave.)</td>
</tr>
<tr>
<td>FATİH</td>
<td>Tüm malzemenin %25-30 tuğla kırğı ve tozu, %65-70’i kuartz aggregasıdır. 1mm elek üstündeki kalan agreganın max./cgi: 8mm dir.125 mikron altı toz boyutu fazladır. Kireç agreganın oranı %5 civarındadır.</td>
<td>%30 Hidrolık Özellikli Kireç</td>
<td>%70 (%25 kireçtaşı, %25 tuğla kırığı, geri kalani kuartz aggregasi, 5mm elek alt ve kırışımın %10-15’i kadar 8mm-1cm arası kuartz aggregasi ve tuğla kırığı ilave.)</td>
</tr>
</tbody>
</table>
2.3 TARİHİ KÖPRÜLERDEN ALINAN ORJİNAL AHŞAP MALZEMELERİNİN DEĞERLENDİRİLMESİ

Özellikle Selçuklu ve Osmanlı Dönemi Köprülerinin birçokunun temel sistemlerinde, taşıma gücü zayıf ve tabanı gergin malzemeden oluşan zeminlerde ahşap kazıklar, sağlam zeminlerde ise ahşap izgaralar kullanılmıştır. Izgaralar ile temel altında büyük boyutlu 'elastomer mesnet' teşkil etti, zemin ile yapının taban arasında esnek enerji sönmüleyici elamanlar yerleştirilerek, zeminden yapıya aktarılan deprem kuvvetleri azaltılmıştır. Figür 10

Figür 10 Ahşap Kazıklar

Edirne İlinde Meriç ve Kanuni Köprüsünün temel sisteminde kullanılan ahşap kazıkların anatomik, fiziksel ve mekanik inceleme neticesinde aşağıdaki sonuçlar tespit edilmiştir. (İstanbul Üniversitesi 2007)

<table>
<thead>
<tr>
<th>FİZİKSEL ÖZELLİK</th>
<th>Yeni ahşap malzeme</th>
<th>Meriç Köprüsü Özgün Malzeme</th>
<th>Kanuni Köprüsü Özgün Malzeme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rutubet %</td>
<td>90</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Yoğunluk g/cm³</td>
<td>0,70</td>
<td>0,98</td>
<td>0,97</td>
</tr>
<tr>
<td>Daralma</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radyal</td>
<td>4,2</td>
<td>9,5</td>
<td>11,4</td>
</tr>
<tr>
<td>Teğet</td>
<td>7,2</td>
<td>14,2</td>
<td>16,3</td>
</tr>
<tr>
<td>Boyuna</td>
<td>0,3</td>
<td>0,4</td>
<td>0,3</td>
</tr>
<tr>
<td>Hacimsel</td>
<td>11,7</td>
<td>24,2</td>
<td>28,1</td>
</tr>
<tr>
<td>MEKANİK ÖZELLİK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liflere dik basınç direnci</td>
<td>11,07</td>
<td>10,13</td>
<td>8,9</td>
</tr>
<tr>
<td>Liflere Paralel basınç direnci</td>
<td>43,72</td>
<td>38</td>
<td>28,07</td>
</tr>
</tbody>
</table>

Ak meşe grubuna giren ağaç malzemenin yoğunluk değeri 0,97 g/cm³ olup, literatürde aynı meşelerin 0,70g/m³ olduğu görülmektedir. Yoğunlukta farklılık nedeni ağac malzeminin uzun süre liflere dik yönde yük etkisi altında kalmadan kaynaklanmaktadır. Ayrıca % 40 lik yoğunluk artış, hücre çeperindeki deformasyonların ve kısmen kirlamaların habercisi olabilir. Yoğunluk artışına bağlı olarak malzemnin daralma (çalışma) değerleri yükselemiş, ancak direnç değerleri düşmüştür. Ahşap malzemenin köprüde kullanım yeri bakımından önemli arz eden liflere dik basınç değerlerindeki kayıpların, bu değerler emniyet gerilmesi değerlerinin (1. Smf meşe için 3N/mm²) üzerindektir. Liflere paralel basınç değerlerindeki kayıplar da emniyet gerilmesi değerlerinin (1. Smf meşe için 12N/mm²) üzerinde kalmıştır. Ahşap kazık ve izgaraların tahrip olması gibi büyük etken olarak, nehir taban seviyesinde meydana gelen değişiklikler sonucu aşıpların açığa çıkması ve hava ile temas, iklim, nem koşulları, strüktür sistemi hataları, yanılış malzeme seçimi vs sıralanabilmekektir.
3 GENEL DEĞERLENDİRME VE SONUÇ
Taş kemer köprülerin özgün yapım sistemleri incelendiğinde; taşıyıcı sistemleri oluşturan temel, ayak ve kemerlerin sağlam kaya ya da 'elastomer mesnet görevi gören enerji sönmüleyici esnek bağlantı sistemleri üzerine (ahşap ızgara ya da ahşap kazık) oturtulduğu dolayısı ile zeminden yapıya aktarılan deprem kuvvetlerinin azalğı olduğu görülmektedir.

Orijinal harç dayanım değerlerini sağlayan harçların onarımda kullanılması durumunda; malzemeaderan, elastlik, mekanik davranış vb. yönderen yapım ile uyumunun sağlanarak, köprü bünüyesinde meydana gelecek rizikli ve zamanla oluşacak yapısal hasarlarnın önlenmesi, hem de onarım maliyeti azalacağı sonucuna varılmıştır. Son yıllarda eski eserlerin güçlendirilmesi amacıyla yüksek oranlarda kullanılması tavsiye edilen harçların, zamanla yapıya olan etkilerinin tespiti ile yine önerilen yeni teknoloji ürünü çekme elamanlarının zaman içindeki olası deprem davranışlarının yapılacak deneysel çalışmalar sonucunda daha iyi anlaşılabilme ve restorasyon uygulamalarının daha sağlıklı bir şekilde yürütülmesine imkan vereceği düşünülmektedir.

Harçların uzun yıllar su ve farklı içerikli karışımlara maruz kalmış olduğu düşünülünce halen yüksek dayanımını olması, kullanılan bağlantıların çok kaliteli ve su dayanım yüksek hidrolik özellikli bir bağlantı olduğu görülmuştur. Köprü harçları genel olarak yüksek dayanıklıdır. Köprülerde metal bağlantı elamanlar oldukça dövme demirden kastet ve zıvantaların kastet ile birliktle kullanılması sağlanmıştır. Tunca ve Meriç Nehirlerinde yataklarında 6–18 metre civarında kum, kil ve alüvyon tabakaları mevcut olup, köprü temellerinin sağlam zemine oturtulması mümkün olmadığından, taşı temelleri inşa edilmiştir.

Sonuç olarak; depremlerin, barajların, değişken su akışlarının, yoğun taşıt trafiği gibi unsurların yarattığı etkiler karşısında dayanımı zayıflatmayan en az müdahale ilkesine bağlı olarak, yapısal hasara karşı korunmak için, yapıda meydana gelen hasara müdahale edilmesi ve bu müdahale ile meydana gelen hasara uyumlu malzeme seçimi yapılır. Bu açıdan restorasyonda köprüünün orijinal malzemeleri ile uyumu malzeme seçimi dikkate edilmelidir.

4 KAYNAKLAR
PAPER TITLE | Kuzey Marmara Otoyolu Kapsamında Tasarlanan Büyük Sanat Yapıları
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TRACK

<table>
<thead>
<tr>
<th>AUTHOR (Capitalize Family Name)</th>
<th>POSITION</th>
<th>ORGANIZATION</th>
<th>COUNTRY</th>
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<tbody>
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<td>Necdet ÇİLİNGİR</td>
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<td>EMAY Uluslararası Müh. ve Müş. A.Ş.</td>
<td>TÜRKİYE</td>
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<td>S. Şehnaz AKTAŞ</td>
<td>İnşaat Yük. Müh. – Harita Müh.</td>
<td>EMAY Uluslararası Müh. ve Müş. A.Ş.</td>
<td>TÜRKİYE</td>
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<tr>
<td>M. Cem DÖNMEZ</td>
<td>İnşaat Yük. Müh.</td>
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<tr>
<td>Esra NAMLI</td>
<td>İnşaat Yük. Müh.</td>
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<td>Gaye Alan JATTA</td>
<td>Jeoloji Müh.</td>
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<td></td>
</tr>
<tr>
<td>Fulya ARACI</td>
<td>İnşaat Yük. Müh. – Çevre Müh.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demir H. YILDIZ</td>
<td>İnşaat Yük. Müh.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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KEYWORDS: Kuzey Marmara Otoyolu, sanat yapıları, köprü, viyadük, tünel.

Kuzey Marmara Otoyolu
Kapsamında Tasarlanan Büyük Sanat Yapıları

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I GİRİŞ


Kuzey Marmara Otoyolu (KMO) Projesi kapsamında yapılacak olan karayolu güzergahı Asya ve Avrupa yakasında otoyol ve bağlantı yolları olmak üzere 4 ayrı bölümden oluşmaktadır (Şekil 1). Güzergah üzerinde 20 adet kavşak, 2 adet tünel (Çamlık ve Riva Tünelleri), 35 adet viyadük, 53 adet üstgeçit, 44 adet altgeçit, 8 adet dere köprüsü ile birlikte 300’e yakın küçük sanat yapısi yer almaktadır.

4 bölümden oluşan güzergahın yer bulduру haritası Şekil 1’de gösterilmiştir.

Şekil 1. Güzergahın yer bulduру haritası
Şekil 1’de verilen güzergah yer bulduğu haritasında güzergah oluşturan böümlere ait kilometreler de Tablo 1’de belirtildiği gibidir:

<table>
<thead>
<tr>
<th>Yaka</th>
<th>Bölüm</th>
<th>Kilometre Aralığı</th>
<th>Amaç</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avrupa</td>
<td>1</td>
<td>0+018,618 – 21+479,093</td>
<td>İstoç – Odayeri</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>61+503,462 – 87+307,639</td>
<td>Odayeri – Garipçe</td>
</tr>
<tr>
<td>Asya</td>
<td>3</td>
<td>88+715,639-123+118,794</td>
<td>Poyraz – Paşaköy</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0+000,000 – 12+764,391</td>
<td>Çamlık - Reşadiye</td>
</tr>
</tbody>
</table>

Kuzey Marmara Otoyolu İşi Kapsamında yapılacak ve 4 bölümden oluşan güzergahta araştırma çalışmaları için arazi gözlemleri, sondaj ve araştırma çukuru çalışmaları ile bu çalışmalarından elde edilen numuneler üzerinde yapılan laboratuvar deney çalışmaları beraber değerlendirilerek güzergahın jeolojisi belirlenmiş ve kritik dolgu, yarma analizleri yapılmış, plevrem ve çukuru buna göre belirlenmiştir. Güzergah üzerinde yer alan tüm sanat yapıları için de (altgeçit, üstgeçit, viyadük ve duvarlar) temellerinin hangi jeolojik birim üzerinde bulunacağı ortaya çıkarılmıştır.

Kuzey Marmara Otoyolu Projesi Boğaz Geçişi kapsamında yapılacak olan Çamlık ve Riva Tüneleri, açılış konumundan Türkiye’de bir ilk özelliği taşımaktadır. Dünyanın en geniş üçüncü, Avrupa’nın ise en geniş tünel konumunda olan iki tünel de her bir tüpü 4 şeritli olmak üzere iki tüplü olarak tasarlanmıştır (Şekil 2). Projelendirilmiş ve imalatı devam etmekte olan otoyolu tüneli orta derinlikte tünel özelliğine sahiptir. 193 m² kazı alanı sahibi olan Riva Tüneli’nin, maksimum kazi derinliği 11 m, maksimum kazi genişliği ise 21 mdır. 225 m² kazı alanı sahibi olan Çamlık Tüneli’nin ise, maksimum kazi derinliği 13 m, maksimum kazi genişliği ise 21 m’dir. Beklenen trafik hızı 80 km/sa olan Riva Tüneli sağ tüpü 564 m, sol tüpü ise 624 m uzunluklarındadır. Trafik hızı 80 km/sa olan Çamlık Tüneli ise sağ tüpü 651 m, sol tüpü ise 552 m uzunluklarındadır. Farklı kaya birimlerinde açılacak olan tünel, NATM kazi tekniği ile açılmaktadır. Farklı dayanımlara sahip olan iki tünel farklı aşağı materalarına ve destekleme tiplerine sahiptir.


2 V26 ve V27 VIYADÜKLERİ

Kuzey Marmara Otoyolu Projesi kapsamında yer alan V26 ve V27 Viyadükleri sirrayla 1005.10 m 25 açılık ve 782.25 metre 19 açılıktadır. Viyadüklerin her bir açılığı 43 metre, genişlikleri ise 22 şer metredir. Ayak yükseklikleri

*Şekil 2. Tünel Enkesiti*
ise maksimum 50 metredir. Bu viyadukler 4’er şeritli taşıma yolları üzerinde olup kuzey ve güney taşıma yollarında birer adet olarak tasarlanmıştır (Şekil 3).

Riva deresi vadilerinin geçildiği bu viyadukler için yapılan jeolojik ve jeofizik araştırma çalışmalarında ana kaya üzerine kalınlığı 40 m civarında çökelmiş Riva deresi güncel alüvyonlarına üzerine oturduğu görülmüştür. Ayrıca sahanın 2. derece deprem bölgesi içerisinde yer aldığı, dolayısıyla sıvılaşma riski yüksek olduğu belirlenmiştir. Bu sebeple viyaduk temelleri için özel geoteknik çözümler önerilmiştir.


![Şekil 3. V26 ve V27 Viyadük lokasyonları](image3)

![Şekil 4. V26 Viyadüğü jeoloji haritası](image4)

Açıklamalar

- **Sondaj Yeri**
- **Alüvyon........(Qal)**
- **Saryer Formasyonu........(Üst Kretase)**
- **Kumtaşı ve volkanik Kayış Topluluğu... (Ks)**

Şekil 3. V26 ve V27 Viyadük lokasyonları

Şekil 4. V26 Viyadüğü jeoloji haritası
Çalışma alanında güzergâh hattı olarak planlanan hat üzerinde farklı derinliklere 11 adet sondaj ile 6 hatta jeofizik çalışmalar yapılmıştır. Tablo 2’de viyadük için yapılan sondajlardan vadi tabanında alüvyon kesilence ait özel tablo verilmiştir.

Tablo 2. Sondajlarda kesilen alüvyon birimine ait SPT değerleri

<table>
<thead>
<tr>
<th>SONDAJ NO</th>
<th>ALÜVYON KALINLIĞI</th>
<th>SPT N_{30} DEĞERLERİ</th>
<th>LİTOLOJİ</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS-74</td>
<td>36 m</td>
<td>11-9-10-7-7-13-7-10-15-15-16-19</td>
<td>Az kumu KİL</td>
</tr>
<tr>
<td>AS-75</td>
<td>37.5</td>
<td>12-20-32-13-5-4-4-5-6-6-5-4-5-5-5-5-6-8</td>
<td>Siltli KUM ve Az Kumu KİL</td>
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<tr>
<td>AS-76</td>
<td>30 m</td>
<td>13-17-13-8-12-11-8-8-13-14</td>
<td>Siltli KUM ve Az Kumu KİL</td>
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</table>


Hat başı ve sonundaki atış uzaklıkları 1.0m’ dir. Hatlardan, viyadük eksenine paralel olarak dizilmiş ve KS1, KS2, KS2a, KS3, KS4 ve KS4a olarak adlandırılmıştır. Yapılan sondajlar ile jeofizik çalışmalar karşılaştırıldığında birbir ile uyumlu olduğu gözlenmişdir.

V26 ve V27 Viyadüklerinde geoteknik ve statik hesaplamlara altlık teşkil etmesi amacıyla Plaxis 2D yazılımı ile zaman tanım alanında doğrusal olmayan hesap yapılmış ve 475 yıllık ortalama yinelenme periyoduna tekbab eden (50 yılda așılma olasılığı %10 olan deprem) tasarım spektrumu uyumu olarak öncelikli kılan 3 takım yarıştırmıyor Türkiye ve Deprem Araştırma Enstitüsü tarafından Kuzey Marmara Otoyolu V26 ve V27 Viyadükleri için yere özel deprem yer hareketleri çalısması yapılmıştır.

Yapılan analizler sonucunda V26 ve V27 Viyadüklerinin özellikle alüvon birimleri içerisinde kalan ayaklar için sıvılaşma riskine karşı güvenlik sayısının artırılması ve zeminde oluşan kayma gerilmelerinin bir kısmının taşınarak deprem sonucu oluşabilecek düşey ve yanal deformasyonların sınırlandırılması amacıyla jet-grout kolonların yapılması önerilmiştir.

Bu viyadükler için öncelikle jet-groutsuz durum için; Plaxis 2D yazılımında, üstüyapının kütlesiz olarak modellenmesi ile doğrusal olmayan hesap yapılmış ve her ayagın temel seviyesinde deplasman-zaman değerleri elde edilmiştir. Ancak jet-groutsuz yapılan analizlerde maksimum moment değerlerinin alüyon kaya birim sınırlarında ortaya çıktığı görülmüştür. Bu nedenle üstteki yer altı suyu yüksek alüyon birimleri içerisinde kalan ayaklar için sıvılaşma riskine karşı güvenlik sayısının artırılması, zeminde oluşabilecek kayma gerilmelerinin bir kısmının taşınarak deprem sonucu oluşabilecek düşey ve yanal deformasyonların sınırlandırılması amacıyla jet-grout (JG) kolonlu analizler yapılmıştır. Jet-grout kolonlu çözümlerde üstteki alüyon biriminin kohezyon ve serbest basınç mukavemeti artırılmış, böylece zemin iyileştirme öncesi durumuna göre daha riyet hale gelmiş olup, tasima gücü artmış muhtemel oturmalarda da azalmıştır.


Aşağıda V26 viyadüğü için sırasıyla Şekil 6, Şekil 7 ve Şekil 8’de Plaxis 2D yazılım ile hazırlanan model, toplam yatay deplasman dağılımı ve Düzce deprem kaydı ile hesaplanan deplasman-zaman grafiği verilmiştir.
Şekil 7. V26 Viyadüğü Toplam Yatay Deplasman Grafiği

Şekil 8. Deprem kaydı (Düzce) için deplasman-zaman grafiği
3 SONUÇ

Kuzey Marmara Otoyolu Yap-İşlet-Devret Modeli ile ihale edildiğinden projenin durumu sebebiyle kısa sürede bitirilmesi istenmiştir. Bu durumun imalat kalitesi ve süresine olumsuz yönde etki yapmaması için tüm önlemler alınmaya çalışılmış ve ülkemiz için prestij projesi olarak tasarruf edilebilecek olan Kuzey Marmara Otoyolu tasarım çalışmalarının büyük bir titizlikle yürütülmüştür.

4 KAYNAKLAR

# NİSSİBİ KÖPRÜSÜ YAPIM AŞAMALARI

<table>
<thead>
<tr>
<th>PAPER TITLE</th>
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<td>TÜRKİYE</td>
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<td>TÜRKİYE</td>
</tr>
</tbody>
</table>

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### ANAHTAR SÖZCÜKLER:

Köprü, Eğik-Gergin Kablo Askılı Köprü, Köprü Yapım Aşamaları

### ÖZET:

NİSSİBİ KÖPRÜSÜ YAPIM AŞAMALARI

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1 GİRİŞ


Şekil 1. Nissibi Köprüsünün güzergah planı

2 KÖPRÜNÜN TANINI VE TASARIM PRENSİPLERİ


Köprüün üstü Yapı genişliği ve yüksekliği sırasıyla 24.50m ve 2.70m’dir. Köprüde ters Y tipi 2 adet 98.8m yüksekliğinde pilonlar bulunmaktadır.( Şekil-5). Eğik kabloların ankrajlandığı bölgede Pilon çelik çekirdek ile kompozit kesit olmaktadır. Değiştirilmiş “ Fan “ sisteminde düzenlenenen kablolar üstte aktif ankraj, altta pasif ankraj uygulanmıştır. Etkiyan kuvvetlere bağlı olarak seçilen kablolar HDPE kılıf, 7x0.6” lik galvanizli tellerdens oluşmaktadır. Konsol segmentler: 2 x(0.6m+3.5m+10x18m+anahtar segment 5.9m) = 380m olarak oluşturulmuştur.

Betonarme ve Çelik üstü, her bir Pilona 40’ar adet toplam 80 adet eğik çelik kablo vaştırıyla asılmıştır.
Ortotropik çelik döşeme olan hafif ana açıklığı dengelemek için ağır betonarme kenar açıklıklar tasarlanmıştır.

Kenar açıklık
Ard-germeli betonarme döşeme

Ana açıklık
Ortotropik Çelik döşeme

Kenar açıklık
Ard-germeli betonarme döşeme

Şekil 2. Nissibi Eğik-Gergin Kablo Askılı Köprü'nün yapışal sistem genel görünüşü

Şekil 3. Ana açıklık ortotropik çelik döşeme tipik en kesiti

Şekil 4. Ortotropik çelik döşeme ve betonarme döşeme birleşimi en kesiti
Şekil 5. Ters Y tipi pilonların sistem görünüşü

Köprü kenarında çekme kuvveti ilave önlem olarak, üst yapı kenarayak içine sokularak düşey hareketi engellendirmiştir. Bu durum, üst yapı ile kenarayak arasına pot mesnet konularak sağlanmıştır. Seçilen pot mesnetin kapasitesi 110 no'lu kablonun düşey bileşenine göre belirlenmiştir ve 4000 kN'dır.
Şekil 6. Üst yapı ile kenarayak arasında yerleştirilen pot mesnet

3 TASARIM

Köprünün çelik ve betonarme yapının tasarımını AASHTO (American Association of State Highway and Transportation Officials) yönetmeligiine uygun olarak gerçekleştirilmiştir.

Yükler:

Hareketli yükler, Tablo 1 ve Şekil 7 da gösterildiği gibi Şerit azaltma çarpanları ve dinamik yükler dahil dilerek (EN-1991-2 4.3.2) modellenmiştir.

Şekil 7. Hareketli yük şerit dağılımı

Tablo 1. Hareketli yükler

<table>
<thead>
<tr>
<th>Lane no.</th>
<th>TS Axle load ( Q_k ) (KN)</th>
<th>UDL ( q_{ks} ) (KN/m²)</th>
<th>UDL ( q_{kl} ) (KN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>300</td>
<td>9</td>
<td>31.5</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>2.5</td>
<td>8.75</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>2.5</td>
<td>8.75</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>2.5</td>
<td>8.75</td>
</tr>
<tr>
<td>Outside lanes</td>
<td>0</td>
<td>2.5</td>
<td>8.75</td>
</tr>
</tbody>
</table>
Diğer yükler ve etkiler meteorolojik verilere uygun olarak belirlenmiştir. Maksimum ve minimum sıcaklıkları $T_{max}=42^\circ C$, $T_{min}=-24^\circ C$, Yapım (referans) sıcaklıkları: $T_{ref}=10^\circ C$. Rüzgar yükü: Tabliye yüzeyinde tasarım rüzgar hızı 33,6 m/s. Deprem Tasarımı: KGM’nin öngörüduğu güvenlik performans seviyesine karşılık gelen 50 yılda aşılma olasılığı %2 (yinelenme süresi 2475 yıl) olan deprem seviyesine göre tasarlanmıştır.

Malzemeler: Beton C30/37 – C50/60, Beton çeliği (Ø 16-32 mm), fyk=500 MPa, Orthotropik Çelik Tabliye: S355 J2 (EN10025), fyk=355 MPa, Eğik-gergin kablo Grade1860, Ø15,7mm (düşük gevşemeli), 7 telli halat, Akma dayanımı =1600 N/mm², Kopma dayanımı =1860 N/mm²
Ard-germe sistemi: Şıra 1860, Ø15,7mm (düşük gevşemeli), 7 telli halat, Akma dayanımı =1670 N/mm², Kopma dayanımı =1860 N/mm²
Öngerme Çelikleri: Akma dayanımı =835 N/mm², Kopma dayanımı =1030 N/mm²

4 KÖPRÜNÜN YAPIM AŞAMALARI

Nissibi Köprüsünün yapım aşamaları Şekil 8, Şekil 9, Şekil 10, Şekil 11’dede gösterilmiştir.

Aşama 1: Pilonların yapımı, 3. ve 5. Açıklıklarların yapımı
Aşama 2: Pilonların yapımı, 2. ve 6. Açıklıklarların yapımı
Aşama 3: Pilonların yapımı, 1. ve 7. Açıklıklarların yapımı

Şekil 8. Aşama 1,2,3

Aşama 4: Ana Açıklığın ilk segment imalatının yapılması
Aşama 5: Ana Açıklık ilk segmentinin kaldırma operasyonu
Aşama 6: Ana Açıklık diğer segmentlerinin kaldırma operasyonu

Şekil 9. Aşama 4,5,6
Aşama 7: Son segmentin (kilit segmentin) konsol segmentlerle bağlantısı

Şekil 10. Aşama 7

Aşama 8: İlave işlerin yapılması

Şekil 11. Aşama 8

5 TEK ASKI HALAT SİSTEMİNİN MONTAJ AŞAMALARI

Tek kablonun yerleştirilmesi Şekil 12’de gösterilmiştir.

1-Halat üst (aktif) ucunun hazırlanması
   - Tek halat kılıfinin (HDPE) sıyrılması
   - “king wire” kral telinin ortaya çıkarılması
   - “king wire” kral telinin kavrama üretimi

2-HDPE boru içinde halatın yerleştirilmesi
   - Halatın vinçe bağlanması
   - Halatın HDPE borunun içinde sürümesi
   - Üst (aktif) ankraya doğru halatın çekilmesi
   - Kamaların yerleştirilmesi

3- Halat alt (pasif) ucunun hazırlanması ve yerleştirilmesi
   - Tek halat kılıfinin HDPE sıyrılması
   - klavuz tele halatın bağlanması
   - Halatın alt (pasif) ankraya doğru çekilmesi
   - Kamaların yerleştirilmesi

4-Halatın gerilmesi
   - Halatların kriko ile halat çekme dayanımının %10 una eşit kuvvetle ( %10 GUTS ) gerilmesi
5- Halatların teker teker yerleşirilmesi (1 den 4 e kadar yapılan aşamalara göre)

6- Tüm kabloların yerleşirilmesinden sonra uygulanan germe işlemi
- bütün halatların halat çekme dayanımının %10 una eşit kuvvetle ( %10 GUTS ) gerilmesi
- “Yükleme” operasyonu –Kablodaki halatların en az %30 unun kuvvet kontrolü
- aynı uzamayı sağlamak için her halatın gerilmesi - Her halattaki nihai kuvvet yaklaşık olarak çekme dayanımının %24 kadar olmalıdır ( %24 GUTS ).
- “Yükleme” operasyonu

Şekil 12. Tek kablonun yerleştirilmesi

6 DANIŞMANLIK VE KONTROLLÜ HİZMETLERİ

Emay, Nissibi Köprüsü inşaattı içinde müsavırlık ve kontrollük hizmetleri kapsamında aşağıda belirtilen konularda çalışmaların sözleme ve şartnamelere uygun şekilde yürütülmesine katkıda bulunmuştur.

1- İşlerin onaylı iş programına göre ilerlemesi, yüklenici firmanın yeterli iş gücü ile makine ve ekipman teminin denetimi.

2- Gerekli malzeme kalite kontrol testlerinin yaptırılarak onaylı malzeme kullanımının sağlanması, ardıçık ve öngörü kablolari ile eşik askı kablolardan kalite kontrol testlerinin gerçekleştirilmesi.

3- Ataşman, röleve vb. belgelerinin düzenli olarak tutulması ile bunların güncellenmesi ile ilgili kontroller.

4- Onaylı uygulama projelerinde yapımdan kaynaklanan zorunluluklar nedeniyle meydana gelen gerekli revizyonların kontrolü ve onaylaştırılması.

5- Yüklenici firmadan intikal eden yeni birim fiyatlarının incelenmesi gerektiğiinde revize edilmesi ve onaylaştırılması, yapım işlemlerine ait hakediş raporlarının kontrolü ve onaylaştırılması.

6- Maliyet artışına ilişkin “mukayeseli keşif” hazırlatılması, kontrolü ve onaylaştırılması.

7- Çalışmaların gerek işveren Karayolları İdaresi, Yüklenici Gülsan A.Ş. gerekse Çevre ve Kamu kuruluşları ile koordineli bir şekilde yürütülmesinin sağlanması.

8- Şantiyede gerekli tüm iş güvenliği koşullarının sağlanması hususunda yüklenicinin denetimi.
7 SONUÇ


8 REFERANS DOKÜMAN VE YÖNETMELİKLER

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- CEB-FIP Bülten No 33, (Aralık 2005) FIB Tavsiyeleri – Ardgerme Halatlarının Dayanıklılığı,
**PAPER TITLE**
EAO Cürufunun Karayolu Üstyapısında Kullanımının Araştırılması; Türkiye Örneği

**TRACK**
G.1 Sustainable Road Construction

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<tbody>
<tr>
<td><a href="mailto:fyonar1981@gmail.com">fyonar1981@gmail.com</a></td>
<td></td>
</tr>
</tbody>
</table>

**KEYWORDS:**
Çelikhan Cürufu, Yapay Agrega, Karayolu Üstyapısı, Süremlülebilirlik

**ABSTRACT:**
Gelişmiş, çok ülkede olduğu gibi, Türkiye’de de, kaynakların ve doğal alanların tüketimini azaltabilmek ayrıca çevresel etkileri indirgeyebilmek bağlamında, konuya ilgili farklı seçeneklerin değerlendirilmesi alınması gerekmemektedir. Çok sayıda araştırma ve uygulama, seçenekler arasında yer alan “Cürufun Karayolu İnşaatında Agrega Olarak Kullanımı”ni öne çıkarmaktadır. Tüm dünyada olduğu gibi, Türkiye’de de demir-çelik sanayii yan ürünü olarak elde edilen cüruf, en yüksek üretim kapasitesine sahip yapay agregadır.

2013 yılı istatistiklerine göre ülkemiz, toplamda 49,6 milyon ton ham çelik üretim kapasitesi ile dünyanın en büyük 8. çelik üreticisi konumundadır. Belirtilen bu kapasitenin %75,9’u elektrik ark ocağının (EAO), %24,1’i ise entegre tesislerin bünyesindedir. 2013 yılı sonunda sektörde faaliyet gösteren 29 tesisin, 9’si Akdeniz bölgesinde, 8’i Marmara bölgesinde, 7’si Karadeniz bölgesinde, 3’ü Ege bölgesinde, 2’i de iç Anadolu bölgesinde yer almaktadır. Bu 29 tesisin 3’ü entegre tesis, 1’i induksiyon ocağı, diğerleri ise EAO’dur.

EAO’lar bünyesinde üretilen ham çelik miktarının %12-15’i arasında çelikhan cürufu ortaya çıkmaktadır. 2013 yılı çelik üretim miktarı dikkate alındığında ise sadece 2013 yılı içerisinde 4 milyon ton çelikhan cürufunun EAO’dan elde edildiği görülmektedir. Uluslararası literatürde yan ürün olarak kabul edilen çelikhan cürufunun Türkiye’de her hangi bir alanda kullanımı henüz sağlanamamıştır. Bu kapsamda çelikhan cürufunun, uluslararası örneklerde olduğu gibi karayolu inşaatında kullanımının sağlanması önem taşımaktadır.

Bu çalışma kapsamında EAO’ların bulunduğu bölgelerden birer tesis seçerek, bu 3 tespit EAO çelikhan cüruf numuneler alınmıştır. Alınan numuneler Karayolları Teknik Şartnamesi 2013 kapsamında granüler temel ve bağılayıcı tabakalarla ilişkin temel deneyler dahilinde incelemiştir. Elde edilen sonuçlar ve öneriler çalışma sonunda sunulmuştur.
EAO Cürufunun Karayolu Üst yapısında Kullanımının Araştırılması; Türkiye Örneği

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1 GİRİŞ


Bu çalışma kapsamında üç farklı bölgedeki çelik üreticilerinden üç EAO çelikhaneye cüruf numunesi ve karşılaştırma yapılabilmesi için Ömerli-Alyans Taşocağı’ndan mineral agregat numunesi alınmıştır. İlk olarak alınan numunelerin kimyasal içerikleri incelenmiş, çelikhaneye cürufunun kullanımını da, alet ve temel kabaca yapay agregat olarak kullanılmaları, çelikhaneye cürufunun kullanımını önem taşımaktadır. Bu araştırma çelikhaneye cürufun çevresel etkileri değerlendirilmiştir, sonuçlar Karayolları Teknik Şartnamesi 2013 limitleri uyarınca değerlendirilmiştir. EAO çelikhaneye cürufun çevresel etkileri incelenmiş, son olarak bunun üzerinde değerlendirme yapmak ve öneriler sunulmuştur.

2 MALZEME ve METOT

Bu çalışma iki ana bölüme ayrılmıştır. İlk bölümde numunelerin kimyasal ve fiziksel özellikleri incelemiştir, ilgili bölümler numunelerin kimyasal ve fiziksel özellikleri incelenmiştir, fiziksel özellikleri Karayolları Teknik Şartnamesi 2013 limitleri uygunca değerlendirilmiştir. İkinci bölüm ise EAO çelikhaneye cürufun çevresel etkisi incelemiştir.
2.1 Malzeme


Mineral agreganın ve EAO çelikhanesinde cüruf numunelerinin kimyasal içerikleri XRF ile belirlenmiştir, elde edilen sonuçlar Tablo 1’de verilmiştir.

Tablo 1. Numunelerin Kimyasal İçerikleri

<table>
<thead>
<tr>
<th>Numune Adı</th>
<th>Metalik Fe (%)</th>
<th>Toplam Fe (%)</th>
<th>FeO (%)</th>
<th>SiO₂ (%)</th>
<th>Al₂O₃ (%)</th>
<th>Toplam CaO (%)</th>
<th>Serbest CaO (%)</th>
<th>MgO (%)</th>
<th>MnO (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAON1</td>
<td>19,1</td>
<td>51,3</td>
<td>32,3</td>
<td>4,7</td>
<td>2,2</td>
<td>17,7</td>
<td>0,2</td>
<td>5,1</td>
<td>3,9</td>
</tr>
<tr>
<td>EAON2</td>
<td>2,9</td>
<td>23,8</td>
<td>20,9</td>
<td>17,9</td>
<td>7,9</td>
<td>39,3</td>
<td>1,0</td>
<td>2,7</td>
<td>4,9</td>
</tr>
<tr>
<td>EAON3</td>
<td>11,0</td>
<td>28,9</td>
<td>17,9</td>
<td>15,0</td>
<td>7,4</td>
<td>34,1</td>
<td>0,6</td>
<td>1,9</td>
<td>3,0</td>
</tr>
<tr>
<td>MAN</td>
<td>0,2</td>
<td>0,8</td>
<td>0,5</td>
<td>0,9</td>
<td>0,4</td>
<td>32,5</td>
<td>0,2</td>
<td>22,1</td>
<td>0,1</td>
</tr>
</tbody>
</table>

Tablo 1’de de görüldüğü üzere tüm parametreler her numune için farklılık arz etmektedir. Bu farklılıklardan ziyade EAO çelikhanesinde cüruf için dikkat edilmesi gereken en önemli parametreler serbest CaO ve MgO içerikleridir. Bu parametreler hidratasyonları sırasında potansiyel genleşmeye neden olmaktadır. Dolayısıyla EAO cürufun karayolu inşaatında kullanılmak için CaO ve MgO temel kimyasal parametre konumundadır.

2.2 Fiziksel Özellikler

İlk olarak numunelere ASTM C127-12 ve ASTM C128-12 su absorbsiyonu ve birim hacim ağırlık deneyleri yapılmıştır. Elde edilen sonuçların ortalaması Tablo 2’de sunulmuştur.

Tablo 2. Birim Hacim Ağırlık ve Su Absorbsiyonu Değerleri

<table>
<thead>
<tr>
<th>Numune No</th>
<th>Boyutlar</th>
<th>BHA (gr/cm³)</th>
<th>Su Absorbsiyon (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAON1</td>
<td>İnce</td>
<td>4,45</td>
<td>2,73</td>
</tr>
<tr>
<td></td>
<td>Kaba</td>
<td>4,37</td>
<td>4,19</td>
</tr>
<tr>
<td>EAON2</td>
<td>İnce</td>
<td>3,51</td>
<td>2,39</td>
</tr>
<tr>
<td></td>
<td>Kaba</td>
<td>3,70</td>
<td>4,08</td>
</tr>
<tr>
<td>EAON3</td>
<td>İnce</td>
<td>3,57</td>
<td>3,18</td>
</tr>
<tr>
<td></td>
<td>Kaba</td>
<td>3,59</td>
<td>4,24</td>
</tr>
<tr>
<td>MAN</td>
<td>İnce</td>
<td>2,84</td>
<td>0,44</td>
</tr>
<tr>
<td></td>
<td>Kaba</td>
<td>2,85</td>
<td>0,28</td>
</tr>
</tbody>
</table>

Bunun yanı sıra cürufun kaba tanelerindeki su absorbsiyonu değeri ince tanelerden daha yüksektir. Tanelerin küçülmesi ile gözenekli yapıda belirgin bir azalma olmaktadır.

Karayolları Teknik Şartnamesi 2013 kapsamında; alttemel tabakası için %3,5, temel tabakası için %3, sathi kaplama, bitümlü temel ve binder için %2,5, aşınma tabakası ve taş mastik asfalt için %2 su absorbsiyonu değerleri şartnamede belirtilmiştir. Tablo 2’de verilen deney sonuçlarına göre EAO çelikhane cürufunun su absorbsiyonu değerleri şartnamede belirtilen limitlerin üzerinde indirgenmiştir. Bununla birlikte şartnamede; özel durumlarda, diğer koşulları sağlamak kaydıyla, yüksek su absorbsiyonuna sahip agreganın idarenin onayı ile kullanılabileceğini belirtilmştir.


Tablo.3 Yassılık İndeksi Deney Sonuçları

<table>
<thead>
<tr>
<th>Numune Adı</th>
<th>Yassılık İndeksi (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAON1</td>
<td>9,9</td>
</tr>
<tr>
<td>EAON2</td>
<td>16,8</td>
</tr>
<tr>
<td>EAON3</td>
<td>6,0</td>
</tr>
<tr>
<td>MAN</td>
<td>17,7</td>
</tr>
</tbody>
</table>


Karayolları Teknik Şartnamesi 2013 kapsamında; alttemel tabakası için plastisite indeksinin maksimum %6, diğer tabakalar için ise malzemenin non-plastik olması gereğini şart verilmiştir. Numuneler şartnamede belirtilen limitleri sağlamaktadırlar.

Numunelere ASTM C142 standardı uyarınca kil toplakları ve dağılabilen tane oranı deneyi de yapılmıştır. Elde edilen sonuçlar Tablo 4’te sunulmuştur.

Tablo.4 Kil Topağı ve Dağılabilen Tane Oranı Deney Sonuçları

<table>
<thead>
<tr>
<th>Numune Adı</th>
<th>Dağılabilen Tane Oran (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAON1</td>
<td>0,1</td>
</tr>
<tr>
<td>EAON2</td>
<td>0,3</td>
</tr>
<tr>
<td>EAON3</td>
<td>0,7</td>
</tr>
<tr>
<td>MAN</td>
<td>0,6</td>
</tr>
</tbody>
</table>
Yapılan plastik limit deneyinde cüruf dahilinde kil bulunmadığı belirlenmiştir. Dolayısıyla bu deney dağılabilen tane oranını saptamak için yapılmıştır. Cüruf içeriğindeki dağılabilen tane oranı anhidrate CaO ve MgO’den kaynaklanmaktadır.

Karayolları Teknik Şartnamesi 2013 kapsamında; alttemel tabakası için %2, temel tabakası için %1, bitümlü temel, binder, sathi kaplama ve artışına tabakası için %0,3 kil topağı ve dağılabilen tane oranı limiti verilmiş, taş mastik asfalt için kullanılacak agregada kil topağı ve dağılabilen tane bulunmaması istemiştir. EAON1 ve EAON2 taş mastik asfalt haricindeki limitleri sağlamakta, EAON3 ve MAN ise alttemel ve temel tabakası için verilen limitleri sağlamaktadır.

Mineral agrega numunelerinin non-plastik olması karşın dağılabilen tane oranının şartnamesede verilen limitler üzerinde çıktığı gözlemlemiştir. Bu durumun agrega tanelleri üzerine yapışmış olan filler tanellerinden kaynaklandığı düşünülmektedir.

Cüruf numunelerindeki dağılabilen tane oranı şartnamesi verilen limitlerin üzerinde çıkmıştır. Yeterli yaşlandırma işlemi sonrası CaO ve MgO bileşikleri hidrate olacak ve dağılabilen tane oranı istenen limitlere çekilecektir.

Numunelere ASTM C131 standardı uyarınca parçalanma direnci deneyi yapılmıştır. Elde edilen sonuçlar Tablo 5’tede sunulmuştur.

<table>
<thead>
<tr>
<th>Numune Adı</th>
<th>Parçalanan Tane Oranı (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAON1</td>
<td>21,6</td>
</tr>
<tr>
<td>EAON2</td>
<td>17,3</td>
</tr>
<tr>
<td>EAON3</td>
<td>21,0</td>
</tr>
<tr>
<td>MAN</td>
<td>18,8</td>
</tr>
</tbody>
</table>

Numunelere ASTM C88 standardı uyarınca hava tesirlerine karşı dayanıklılık deneyi yapılmıştır. Elde edilen sonuçlar Tablo 6’da sunulmuştur.

<table>
<thead>
<tr>
<th>Numune Adı</th>
<th>Parçalanan Tane Oranı (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAON1</td>
<td>1,6</td>
</tr>
<tr>
<td>EAON2</td>
<td>1,5</td>
</tr>
<tr>
<td>EAON3</td>
<td>2,4</td>
</tr>
<tr>
<td>MAN</td>
<td>1,5</td>
</tr>
</tbody>
</table>

Numunelere Nicholson metodu uyarınca soyulma mukavemeti deneyi yapılmıştır. Her numune için DOP katkısı ve %0,2 SCG-XL DOP katkılı iki deney gerçekleştirilmiştir. Elde edilen sonuçlar Tablo 7’de sunulmuştur.
Tablo.7 Soyulma Mukavemeti Deney Sonuçları

<table>
<thead>
<tr>
<th>Numune Adı</th>
<th>DOP Katkı Az</th>
<th>DOP Katkı Artan Soyulma Mukavemeti (%)</th>
<th>Soyulma Mukavemeti (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAON1</td>
<td>10-20</td>
<td></td>
<td>50-60</td>
</tr>
<tr>
<td>EAON2</td>
<td>40-50</td>
<td></td>
<td>80-90</td>
</tr>
<tr>
<td>EAON3</td>
<td>30-40</td>
<td></td>
<td>90-100</td>
</tr>
<tr>
<td>MAN</td>
<td>60-70</td>
<td></td>
<td>90-100</td>
</tr>
</tbody>
</table>

Karayolları Teknik Şartnamesi 2013’de tüm bağlayıcı tabakalar için soyulma mukavemeti limiti %60 olarak verilmiştir. Bitüme DOP katkısı ilave edilmeden yapılan soyulma mukavemeti deney sonuçlarının yetersiz kaldığı Tablo 7’de görülmektedir. %0,2 DOP katkısı ile bu değerler istenilen limitler içine çekilebilmektedir.

Ayrıca Tablo 7’de verilen sonuçlar Tablo 1’de verilen kimyasal içeriklerle karşılaştırıldığında, metalik Fe içeriğinin soyulma mukavemetlerini ciddi şekilde etkilediği görülmektedir.

Numunelere ASTM D3319 standardı uyarınca cilalanma deneyi uygulanmıştır. Elde edilen sonuçlar Tablo 8’de sunulmuştur.

Tablo.8 Cilalanma Deney Sonuçları

<table>
<thead>
<tr>
<th>Numune Adı</th>
<th>Cilalanma Değeri</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAON1</td>
<td>59,4</td>
</tr>
<tr>
<td>EAON2</td>
<td>57,7</td>
</tr>
<tr>
<td>EAON3</td>
<td>54,1</td>
</tr>
<tr>
<td>MAN</td>
<td>51,1</td>
</tr>
</tbody>
</table>

Karayolları Teknik Şartnamesi 2013 kapsamında; binder tabakası için 35, sathi kaplama için 40, aşınma ve taş masık asfalt tabakası için 50 cilalanma değeri limitleri verilmiştir. Tablo 8’de görüldüğü üzere numuneler şartnamede belirtilen limitleri sağlamaktadırlar. Ayrıca cüruf numunelerinin cilalanma değerlerinin mineral agregaya oranla yüksekti olduğu görülmektedir.

2.3 Çevresel Etki

Türkiye’de cüruflarla ilgili özel bir çevre mevzuatı bulunmadığından, diğer atıklarda olduğu gibi Atık Yönetimi Genel Esaslarına İlişkin Yönetmelik ile Deneşli Depolama Yönetmeliği bu konuda öne çıkmaktadır. Fakat cürufların yeniden kullanılmasını sağlamak için yasal düzenlemelerde yer alan tapiya dengeleme, tesislerde belirtilen sınırların geçerliliği, atıkların toplanması ve toplandığı yerlerin çevreselجماş kalmaması gibi tedbirler alınmakta ve cürufun yeniden kullanılmasına yönelik yasal düzenlemeler ve uygulamalarla ilgili olarak düzenlemeler de uygulanmaktadır. 

Çelik üretiminde kimyasal reaksiyonlar sonucu meydana gelen oksitlerin gaz halinde olabildiği gibi hydrozomik koşullar altında, zincirlerin birleşmesi sonucu birleşik cüruf oluşması ve tesislerdeki cürufunAPEL ve taş mastik asfalt tabakası için 50 cilalanma değeri limiti verilmiştir. Tablo 8’de görüldüğü üzere numuneler şartnamede belirtilen limitleri sağlamaktadırlar. Ayrıca cüruf numunelerinin cilalanma değerlerinin mineral agregaya oranla yüksekti olduğu görülmektedir.

2.3 Çevresel Etki

köşeli ve yüzeyi pürüzlü bir görünüme sahiptir. Yapılan çok sayıda araştırma belirli bir süre bekletilmiş cürufların çevresel toksisiteye neden olacak nitelikte kimyasal bir bileşen içermemiştiğini göstermektedir.

Cürufların hammadde olarak yeniden kullanımı sayesinde bir yandan normal koşullarda stok sahalarında bekletilen ve büyük kütleler halinde ortaya çıkan bir malzeme sağlıklı biçimde uzaklaştırılmış olmakta, diğer yandan doğal kaynak tüketiminden tasarruf sağlanamaktadır ve çevre sorunları minimuma indirilmektedir.


Tehlikesiz ve inert atıkları ilgilendiren en genel mevzuat 26.03.2010 tarih ve 27533 sayılı Resmi Gazete’dede yayımlanarak yürürlüğe giren Atıkların Düzenli Depolanmasına Dair Yönetmelik’tir. Bu yönetmelik çerçevesinde yapılan tanımlamalar şu şekildedir (ADDDY, 2010):

İnert Atık: Fiziksel, kimyasal veya biyolojik olarak önemli derecede herhangi bir değişim ugraşmayan, çözünmeyen, yanmayan, fiziksel veya kimyasal olarak reaksiyona girmeyen, biyolojik bozunmaya uğramayan veya temas ettiği maddeleri çevreye veya insan hayatına zarar verecek şekilde etkileyemeyen ve toplam�nt su kabiliyeti ve ekotoksisitesi önemsiz miktarında olan, özellikle yüzeysel su ve yeral ses su kirliliği tehlikesi yaratmayan atıklar.

Tehlikesiz Atık: Tehlikeli atık tanımması girmeyen atıklardır.

Demir-çelik endüstrisinden meydana gelen işlememis cüruflar tehlikesiz ve/veya inert atık olarak değerlendirilmektedir.


Bu çalışmayla ilgili temel sonuçlar şu şekildedir: (NSA, 1998)

Cüruf içeriğindeki metallerin sıvı ortama verdikleri bileşikler önemiz düzeyde kaldıgı için yeraltı ve yüzeysel içme suyu kaynakları için tehlike oluşturamaktadır.

Çelıkhanede cürufunun havanlar ve fauna üzerinde belirli bir etkisi bulunmamaktadır. Cüruf içeriğindeki metaller besin zincirinde birikmemektedir.

Çelıkhanede cüruf, nehirler ve göller gibi su ortamlarının kalitelerine ve sucul yaşam olumsuz etkisi olmadığını buralarda güvenle kullanılabilir. Ancak hacimce küçük su ortamlarında yeraltı ve yüzey suyu kaynaklarının değerlendirmesi gerekmektedir (ASA, 2002).

Newcastle Üniversitesi tarafından cürufun stabilize yollarda kullanımıyla ilgili yapılan bir araştırmada cüruf uygulamasından sonra bazı durumlarda sülfür kokusu oluştuğu, ayrıca sızıntı suyunda da sülfür kokusu oluşabileceğini belirtmiştir. Ancak bunun geçici bir durum olduğu gözlemlemiştir. Yeterince havalandırılmış cüruf ardından sülfür kokusu sorununun oluşmadığı tespit edilmiştir (ASA, 2002).

EAO çelikhanede cürufun karayolu inşaatında agrega olarak kullanımındaki olası çevresel etkileri konusunda yapılan çalışmalar bulunmaktadır. Bu doğrultuda özellikle cürufun çevrede olan zehirli etkisini ölçmek üzere ekotoksisite analizleri yapılmıştır. Bu analizlerin sonuçlarına göre EAO cürufu tehlikesiz yan ürün kategorisinde değerlendirilmektedir (Sofilic, Mladenovic, & Sofilic, 2010).

3 SONUÇLAR ve ÖNERİLER

EAO çelikhanede cürufunun uluslararası literatürde yan ürün olarak tanımlanmasında karşın Türkiye’de cürufun değerlendirilmesi ve işlenmesine ilişkin herhangi bir düzenleme mevcut değildir. Bu çalışma kapsamında cürufun temel fiziksel özellikleri incelenmiş ve çevresel etkileri kapsamında literatür taraması yapılmış, edel edilen sonuçlar ve sonuçlara ilişkin önerilerin sunulması sağlanmıştır.


EAO çelikhanede cürufunun yassılık indeksi değerleri mineral aggregaya oranla daha iyidir. Bu durumun ani soğutma esnasında cüruf taneciklerinin küük biçimde parçalanmasından kaynaklandığı düşünülmektedir.

Numuneler içerisinde kile rastlanmamasına karşın cüruf taki CaO ve MgO içerikleri dağılabilen tane oranının sınırlı olduğu düşünülmektedir. Bu durumun cüruf sıvı ortadan kaldırılması için önemlidir. Ayrıca genleşme durumunun ortadan kaldırılması için yapıştırma işlemini izlenmemelidir.

102
Cüruf gözenekli yapıda olmasına karşın bu durum hava tesirlerine karşı dayanıklılığını etkilememektedir.

Cürufun soyulma mukavemeti değerlenen istenilen limitlere çekilebilmek için metalik Fe’in bünüyeden mümkün olduğuna uzaklaştırılması gerekmektedir.metalik Fe’in ayrıştırılması ayrıca tesis içi geri dönüşümde katkıda bulunacak ve üreticilere ekonomik yarar sağlayacaktır.

Yapılan literatür taramasında EAO çelikhane cürufunun yapay agreg olarak kullanılması durumunda su kaynakları açısından bir tehlike oluşturmadığı, halk ve çevre sağlığı açısından bir risk içermemesi, içerisindeki metallerin besin zinciri içinde birikmediği ve ikamesi durumunda doğal kaynak ve alan tüketimini indirgeyebileceğini, mineral agreganın üretimi sırasında oluşan karbon salınımını azaltabileceği belirlenmiştir.

Bu çalışma kapsamında EAO çelikhane cürufunun yapay agreg olarak karayolu inşaatında kullanılabilmesi, yetersiz fiziksel özelliklerinin mekanik düzenlemeler ile istenilen limitler dahiline alınabileceğini ve çevresel açıdan bir etkinin olmamasının yanı sıra ülkemize katkı sağlayacağı belirlenmiştir.

Bu çalışma “Çelik Cürufunun Karayolu İnşaatında Kullanımı, Performansı ve Mevzuat Önerisinin Oluşturulması” (KGM ARGE 2012-7) projesi kapsamında gerçekleştirilmiştir.

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ARE SERVICES PROVIDED TO ROAD USERS … LOST IN TRANSLATION?

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ABSTRACT

The use of Public-Private Partnerships (PPP) as a method of procuring large infrastructure projects has soared during the last few decades. Politicians prefer PPPs over public works, as these allow them to use taxpayers’ money for purposes other than financing, operating and maintaining infrastructure, PROVIDED they can justify and legitimize rates collected by private parties against both superior services offered to Users and positive Stakeholder attitudes.

Thus, PPP’s implement strict contractual obligations that help promote innovation, provide an above-average level of service to Users and accommodate other Stakeholders. In the case of a tolled Road, the concession contract may mandate the level of service provided to meet or even exceed certain standards in the areas of trip Safety, Reliability and Comfort, as well as certain parameters affecting other Stakeholders.

To monitor performance, a toll Operator may implement a variety of indicators (such as KPIs, etc.) used to quantify objectives that reflect strategic and operational performance of the Operating Company (traffic management, toll operation, infrastructure maintenance, HR, violation enforcement, etc.). By monitoring these indicators, the Operator can obtain specific and reliable measurement that describes performance in aspects such as road safety, noise/air pollution etc.

For instance, by monitoring the number of fatal accidents per vehicle-kilometers travelled and comparing this with previous years or with other road projects around the world, the Operator can argue a certain level of road safety on the tollway. However, the perceived level of safety from the User’s point of view can be entirely different. For the User, the number of fatal accidents will probably not influence perceived safety as much as the existence of speeding cars and reckless drivers on the tollway. Similarly, efforts made by the Operator to maintain a clean and healthy environment by monitoring air pollution or extensive planting may not be perceived in the same way by Users, who might value the absence of litter on the road pavement more.

Often, actions carried out and measured by the Road Operator to monitor performance can be “lost in translation”, because Users and other Stakeholders may have a different understanding and perception of the same issue. It is important to know the Users’ opinion, so the Operator needs to ask the Users and collect information regarding their perception of the performance of the Operator and not only rely on what the Operator measures.

This paper aims at identifying cases where Users perceive performance differently and in recommending methods of bridging this difference between Operator measurement and public perception, in order to provide the best possible service to the User and safeguard the project’s Reputation.
1. **INTRODUCTION**

There are four main stakeholders that are involved in a tolled motorway concession:

- **Politicians** seek to balance public funds released by PPP roads against the minimization of frictions caused to stakeholder groups, over the political lifecycle.
- For a **concession**, a complicating factor is the difference between the political and its own lifecycle, which is much longer, as it usually spans two to three decades. Over the longer time-horizon stakes, even stakeholder groups may change, putting initial arrangements under strain.
- To **Users**, called upon to pay toll rates, decision-makers offer the enhanced mobility of operated roads embodied in concession contracts in the concrete form of performance standards, which aim at ensuring specified levels of trip Safety, Reliability and Comfort.
- **Operators** strive to adhere to the concession’s contractual performance obligations by establishing a monitoring system and by gauging objective measures of services provided together with their assessed impact on safety, reliability and comfort. These may include indices on: fatalities per one hundred million vehicle kilometers per year; accidents over incidents; total queuing duration lengths and times; average trip duration between points; average incident response times for own and third party services; lanes closed due to maintenance; effective (preventive over corrective) maintenance; timely restitution of problems; complaints; driver perceived safety feeling; attribution of incident responsibility; repetitive system failures, customer loyalty, customer service satisfaction, etc.

Yet the relationship between toll rates charged by road operators on the one hand and trip Safety, Reliability and Comfort as perceived by Users on the other, is the critical one. This relationship determines the level of User satisfaction and hence the toll road Reputation, as well as the traffic numbers essential for the success of a concession’s financial model, given that an alternative to the tolled road exists. If the tolled road is a “monopoly”, in the sense that there are no alternative routes, imbalances (User dissatisfaction) may invite protests and pressure will rise on (the next generation of) politicians to review concession terms. This will happen because most concession contracts “fix” toll rates and possible changes thereof over the entire concession period, not allowing them to vary in order to absorb eventual mismatches.

In its most abstract form, a concession’s financial model will set User behaviour implicitly. It will do so by assuming a level of disposable revenue that will induce enough Users to choose a trip (in accordance with characteristics such as travel time, travel purpose, trip reliability, safety and comfort) at a rate equal or higher than the toll rates contracted over time. In this way, it will produce the present value of future revenue streams needed for the investment to be worthwhile. In actual fact, 64% of the 276 PPP road projects for which revenue source information was available were funded via (contractually set) user fees in countries as diverse as France, Italy, Portugal, Spain and Greece in Southern Europe, but also Malaysia, South Africa, Croatia, China, India, Brazil, or Indonesia (http://www.ifc.org/wps/wcm/connect/2a4494804e3529f1f887da87ea99d66321/Handshake_Issue8_WEB.pdf?MOD=AJPERES).

To make this assumption more explicit, it purports that GDP growth - a factor exogenous to all agents - will evolve favourably enough to drive the process over two to three decades. It is equivalent to assuming that traffic will never vary with User (customer) satisfaction (in case of dissatisfaction, Users will not opt for the existing alternative) or that they will never question the legitimacy of the tolled road as a privately operated public good (they will keep using the road without protesting even when dissatisfied by the “monopoly”).

Yet evidence in the cases of Greece, Spain, Portugal, France and the UK (there are plenty of similar examples outside Europe too) shows this is not the case. Following concession contracts signed in 2007 in Greece, toll road concessions halted construction due to traffic, protest and financing problems in 2012 and the government revised the contracts in 2013 for construction to start again in

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105
Motorists preferred to use Spain's free national highways during the recession so traffic on the toll roads had fallen nearly 40 percent in the 5-year economic slump (http://www.reuters.com/article/2013/11/28/spain-motorways-rescue-idUSL5N0J53NO20131128). Protests against Portugal’s A22 took on an international flavour involving Spanish Podemos on the Guadiana Bridge, Algarve (http://portugalresident.com/a22-anti-tolls-groups-join-forces-for-another-cross-border-protest).

France’s Socialist government scrapped plans to implement the ecotax and more recently revised what it saw as over-generous concession contracts, which were the result of privatisation undertaken by the previous conservative government (http://citizen.co.za/81432/protesters-burn-french-toll-gantry/ and http://www.reuters.com/article/2015/04/09/france-motorways-macron-idUSL5N0X624P20150409). In the UK, protesters targeted the M6 Toll road calling for the ‘largely empty’ motorway to be nationalised (http://www.birminghammail.co.uk/news/local-news/ukips-m6-toll-road-protest-1761977).

Indeed, this paper will argue that monitoring the perception of a tolled road’s performance (the degree of satisfaction of stakes) by Users and other stakeholder groups and acting upon such insights will protect the tolled road’s reputation. Armed with knowledge, the Operator can devise sets of policies to improve stake satisfaction and thus provide a safety “bumper” for adverse GDP developments, minimise potential risks for contract revisions and safeguard the legitimacy of the concession in the eyes of stakeholder groups and the public opinion at large.

2. FACTORS AND PROCESSES AFFECTING THE FORMATION OF REPUTATION

It is time to form the framework of the discussion by setting out to define concepts and relationships in clearer terms. To keep the argument simple we consider one stakeholder group and one attribute only, Users and trip Safety, although one can extend and generalize the analysis to include all stakeholder groups and many attributes, leading to a meaningful approach to a tolled road’s partial Reputations.

Let User satisfaction at the end of each period depend on perceived delivery of road safety (which may or may not be identical to the Operator’s objective measure or KPI for the same concept) versus the expectation Users held at the beginning of that period.

Users, like every stakeholder group, will compare stake “delivery” - as they perceive it - to their initial expectation in order to determine changes in the Reputation of the tolled road (Harpur, 2002), (Gaultier-Gaillard, Louisot & Rayner, 2009). Defining Reputation by aggregating positive and negative deviations between current perceived experience and prior expectation over time, in combination with stakeholder theory, is quite recent (Mandalozis & Skylakakis, 2013).

A positive difference between experience and expectation when experience exceeds prior expectation will improve the Reputation of the road by a fraction $\lambda$, where $0<\lambda<1$. If, on the contrary, stake satisfaction (“delivery” as perceived) falls short of expectations, then the difference is negative and reputation will deteriorate by its whole amount, i.e. $\lambda=1$.

Intuitively, Warren Buffett, Chairman and CEO, Berkshire Hathaway had warned long ago: “It takes 20 years to build a reputation and five minutes to ruin it. If you think about that you’ll do things differently.” Most economic models of reputation accept the postulate that “negative surprises to a firm’s reputation are punished more severely than positive surprises are rewarded” (Cabral, 2015).

“People’s expectations change over time, albeit slowly. Common sense attributes such change to take place due to “experience”, i.e. accumulation of perceived performances. Out of natural suspicion towards novelty, people may be cautious to credit their expectations at the beginning of next period with the whole part of perceived performance achieved during the previous one, for some number of initial periods. They may credit it with a small part, until they see this happening time and again. When they experience long-term consistency of high perceived performance, this is what they
come to expect. This might help explain why building up Reputation takes quite a long time and requires systematic overshooting in perceived performance.” (Mandalozis & Skylakakis, 2013)

It is therefore legitimate to assume that

$$\Delta R_t = \lambda \cdot [p(S_d)_t - S_{e t-1}]$$

where $0 < \lambda < 1$ for $[p(S_d)_t - S_{e t-1}] > 0$ and $\lambda = 1$ for $[p(S_d)_t - S_{e t-1}] < 0$ [1]

$p(S_d)_t$ represents how safe the users perceive to be on this road after having experienced trips on the tolled road during time period $t$. For them, this is what they perceive the road offers, in terms of safety.

The equation’s other term, $S_{e t-1}$, stands for the expectation users had formed about safety at the beginning of period $t$. $\Delta R_t$ is the conclusion they draw when they compare the two terms, to help them update the road’s safety reputation with experience from period $t$.

3. THE FILTER OF PERCEPTION

Since equation [1] is so central to the argument, let us consider the two possible logical cases. In the first case, let $S_d$ as in $p(S_d)_t$ be identical to the Operator’s actual performance $\Sigma_t$ during period $t$ and $S_{e t-1}$ identical to $\Sigma_{t-1}$, the Operator’s performance in period $t-1$. The road Operator knows both $\Sigma_t$ and $\Sigma_{t-1}$ because they are measured to form the safety performance index or Safety Key Performance Indicator (SKPI) in order to comply with the contract terms. Accordingly, the Operator knows for sure that when $\Sigma_t$ can be made better than $\Sigma_{t-1}$, the road’s Reputation will be improved. Or will it?

Even in the improbable case where users form their safety feeling on the basis of “accidents per one hundred million vehicle kilometers per year” only, there is still the perception factor to take care of. $\Sigma_t$ is not the same as $p(\Sigma_t)$.

One way around this problem is to approximate the perception factor by the ratio of the volume of positive plus neutral (favourable, $C_f$) over the volume of negative (unfavourable, $C_u$) communication (Mandalozis & Skylakakis, 2013). User safety perception then relates to the Operator safety performance index as follows:

$$p(\Sigma_t) = \frac{C_f}{C_u} * \Sigma_t = c * \Sigma_t$$ [2]

One can instruct a monitoring agency to obtain $C_f$ and $C_u$, whose communication volume is measured in Gross Rating Points. As the GRP units cancel each other out, we are left with $\Sigma_t$, the Operator’s safety performance index or SKPI, scaled by a ratio, $c$, where $c>1$, $c<1$ or $c=1$; perceived performance will accurately reflect actual performance only when $c=1$. Employing this hypothesis, the authors offered an explanation for the discrepancies of data available to them:

“One crucial KPI for any road will relate to user safety. In the case of Attiki Odos, this indicator coincides with the Accident Rate, defined as crashes per 100 million vehicle-kms. These accidents are being broken down as related to objects on the road, to moving hazards and to other incidents (for its precise composition and measurement formula, see Table 1). The purpose of this indicator is to provide valuable data that will assist in taking measures to reduce accidents on the Motorway. Attiki Odos had set a target value below “50” for this KPI, which was achieved in 2013 (33.50 was the value for July 2013 versus 56.7 for 2010, 57.4 for 2011 and 55.8 for 2012).
Until 2012, Users’ feeling of safety, as recorded by annual Road Side Surveys (RSS), had been moving in the same direction as the KPI. An unexpected reversal took place in 2013, where, despite the substantial improvement of the specific KPI, the Users’ feeling of safety “deteriorated” from 98.4% in 2012 to 95.3% in 2013 (see Table 2). This is attributed to a well-publicized tragic traffic accident which resulted in the death of a young, well-known Greek television actor in April 2013. The accident has caused a high volume of publicity, distorting the Users’ feeling of safety. This is of course an extreme example of how the Users’ perception of performance does not coincide with the measured

### TABLE 1 KPI relating to Users’ Safety

<table>
<thead>
<tr>
<th>Measurement Results</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013 up to Jul 2013</th>
<th>Jul 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash Indicator</td>
<td>56.70</td>
<td>57.40</td>
<td>55.80</td>
<td>46.80</td>
<td>33.59</td>
</tr>
<tr>
<td>Indicator of crashes due to object on the road</td>
<td>6.30</td>
<td>6.46</td>
<td>7.10</td>
<td>4.70</td>
<td>3.50</td>
</tr>
<tr>
<td>Indicator of crashes due to moving hazard</td>
<td>0.10</td>
<td>0.16</td>
<td>0.20</td>
<td>0.10</td>
<td>0.80</td>
</tr>
<tr>
<td>Indicator of crashes due to accidents</td>
<td>7.20</td>
<td>5.56</td>
<td>5.30</td>
<td>3.70</td>
<td>2.40</td>
</tr>
</tbody>
</table>

**Description & purpose of measurement**

The aim of the indicator is to take measures in order to reduce accidents in the M&N.

**Necessary data for measurement**

<table>
<thead>
<tr>
<th>Data description</th>
<th>Procedure Responsible</th>
<th>Recording interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Number of accidents due to object on the road (b) from file away.</td>
<td>Traffic Management section head</td>
<td>In week of the next month after measurement</td>
</tr>
<tr>
<td>2. Number of accidents due to incident (f) and number of accidents due to moving hazard (h).</td>
<td>KPI Consultant</td>
<td>In week of the next month after measurement</td>
</tr>
<tr>
<td>3. Total veh/km (l) during measurement period.</td>
<td>Traffic Management section head</td>
<td>In week of the next month after measurement</td>
</tr>
</tbody>
</table>

**Summary description of data processing**

From the incidents file, accidents are selected (incident type=4D) and counted. Next, accidents of subtype =0D.a1 = Crash on toll equipments are counted and the difference of the two values is value A. From these accidents, accidents of subtype =0D.a2 = Animal ran over, =0D.a3 = Crash-on-obstacles and =0D.a3 = Object fall are isolated. From the file of accidents due to incidents (Indicator KKY7a), accidents due to incidents of type =0A = Obstacle-Leakage are isolated and accidents that have the above subtypes are deleted, since they have been already counted. Sum of these counts is value B. From the file accidents due to incidents (Indicator KKY7a), number of accidents is value C. From these, the accidents due to original incident "moving hazard" (Type 4E = Moving hazard) are isolated and their count is value Δ. Data concerning crashes on toll equipments are excluded from the calculations.

**Indicator measurement formula**

\[
\frac{\Delta}{B} \times 10^6, \quad \frac{A}{B} \times 10^6, \quad \frac{C}{B} \times 10^6, \quad \frac{\Delta}{E} \times 10^6
\]

### TABLE 2 RSS Result relating to Users’ Feeling of Safety

95.3% state they feel very / quite safe when they drive in Attiki Odos (versus 98.4% in 2012).
performance and a case where the company needs to pursue active communication on the issue of safety to reinstate the balance.” (Mandalozis & Skylakakis, 2013)

To conclude with the first case, even if we can assume the concept of safety employed by Users to be identical to the concept of safety used by the Operator, the latter does not possess enough information to affect Reputation, unless the Operator knows the distortion produced by the perception factor. If this is known, the Operator can engage an optimal mix of road safety measures and communication policies to achieve the desired effect on Reputation and keep road Users satisfied.

4. LOST IN TRANSLATION

The assumption that the concept of safety employed by Users is identical to the concept of safety used by the Operator is quite far-fetched. It requires both the full rationality and the perfect information hypothesis. If the average User does not think like a traffic engineer, it is quite reasonable to examine the second logical possibility. The average User has a vague notion of road safety in his/her head, which is derived from a variety of sources; one of these may be the SKPI, the Operator safety performance index, or it may not. Under such circumstances,

\[ p(S_d) \neq p(\Sigma) \text{ and } S_{\Sigma,1} \neq \Sigma_{t-1} \quad [3] \]

The Operator may still instruct the monitoring agency to gather data on \( C_f/C_u = c \), but the Operator does not know on what magnitude to apply the scalar in order to determine the result of equation [2] and find \( p(S_d) \), so as to replace it in equation [1]. The Operator does not possess the tools to find and influence \( \Delta R_t \). In reality, the Operator does not know how to satisfy road Users.

The Operator works on \( \Sigma \) and plans to improve it, without necessarily being able to affect the road’s safety Reputation positively. This discrepancy may hold true not only for the User safety feeling, but also for any other stakeholders, stakes and attributes relevant to the road’s Reputation.

In fact, when the Operator achieves agreed levels on KPI’s of contractual magnitudes, it is the special case of satisfying the stake of a single stakeholder: the political authority that signed the initial contract. We may call this the “legality” case: the Operator chooses to become entrenched behind the terms of the contract, despite the difference in lifecycles of political authorities, stakeholders and concessions mentioned in the introduction, instead of opting for the legitimacy that can be obtained and sustained by keeping stakeholders satisfied.

5. LOST AND FOUND

Is there a way to find out what the unknown concept of safety in the average User’s mind is? If the Operator can do this, this knowledge can also be extended to cover the User expectation term and thus start measuring each period’s \( \Delta R \). Also, by pinpointing specific aspects of this “subjective” safety concept, the Operator may be surprised to discover that they relate to activities that are undertaken and measured anyway, in order to attain desired values of KPI’s.

One can start with data mining. User complaints, letters, social media comments and the like can uncover hidden treasures. When properly collected, classified and processed, they provide invaluable information about the way Users think and see things. Consider a mild complaint by this pregnant woman driver feeling concerned and anxious “for all these cars overspeeding next to me”. Consider another driver, congratulating the Operator for “the swift rehabilitation of the road lighting” which had fallen out in a specific section, “because it makes driving so much easier at night”.

Operators typically measure average lane speed as a predictor of queue formation. They also regularly measure road lighting performance, in order to comply with specified requirements. Could these be “mapped” onto a User safety feeling? One would have to research available data for possible
areas or factors affecting the User safety feeling, test such concepts as they arise in User focus groups and then quantify the significance of alternative concepts with (a statistically significant sample of) the User population. This is standard work that every marketer does for a consumer product or service. Once the major step of reading the Users’ mind is completed, the Operator only needs to come back and make measurements and updates at regular intervals.

This method also allows the Operator to compare the relative importance of different attributes and determine each stakeholder group’s central stake in an informed way. What is the User group’s central concern or stake with respect to the tolled road, given the level of the toll rate? Is trip Safety more important than Reliability? Is travel time more important than trip Safety and, if so, under what circumstances? The answers to these and numerous other questions will assist the Operator to form a good understanding of the User (and any other stakeholder) group central stake. The Operator will then be able to follow policies that are at the same time helpful in achieving KPIs and meaningful to the groups whose stakes these same KPIs are implicitly aimed at.

6. THE MULTIPLE STAKEHOLDER SETTING

Taking into account the existence of multiple stakeholders and stakes, the Operator faces the following problem: does it make sense to assign relative weights to the satisfaction of stakes of different stakeholder groups in order to arrive at a fair approximation of the tolled roads’ overall or composite Reputation?

Users, both commercial and private, investors, employees, government regulators, roadside residents and businesses, local authorities, the traffic police, the ambulance service, the fire brigade, suppliers, bankers, the media, opinion leaders and influencers, traffic experts and NGO’s, even protesters all have their respective vested stakes with respect to the tolled road.

Although stakeholder theory proposes a number of methods for prioritising stakeholder groups (and consequently the satisfaction of their stakes), this paper takes the view that the concept of overall, or composite Reputation is actually obsolescent for all practical purposes.

The Operator needs to address potential risks to the road’s overall Reputation only to the extent that an unsatisfied stake manages to take central stage in the media and becomes dominant, functioning as a platform for more of the tolled road’s primary stakeholder groups to align themselves behind it and voice their own dissatisfaction and protest. Thus, it does not make sense for the Operator to manage overall or composite Reputation. The Operator can only manage partial stakeholder group Reputations, with an eye not to let any one of them become dominant in the media in a negative sense. The obvious key for such a policy is to monitor partial stakeholder group Reputations closely and form broad alliances of groups with more or less satisfied stakes, minimizing the potential influence of complaints by the odd stakeholder groups by making them the odd ones out.

What tools does the Operator have at his disposal to assess potential stake dominance of the media by any stakeholder group and dynamically adapt his stake satisfaction priorities and respective policies? We have already mentioned them previously: the content and the composition of \( C_t \) and \( C_u \) in terms of the stakes involved in the issues raised reflect both potential media dominance by specific stakes and relative stake importance. By analyzing the terms of the perception factor, the Operator possesses real-time intelligence concerning threats and opportunities, satisfied stakes and less satisfied ones, potential Reputation boosters and dampers.

The Operator can then engage in stakeholder dialogue, devise policies to improve the satisfaction of specific stakes and / or communicate accordingly to avoid the augmentation of negative instances and encourage the prevalence of positive ones. The Operator could even look for predictors of \( C_t \) and \( C_u \) in the same sources used to gain insights on stakeholder stakes and concerns: complaints, letters, social media and press comments, word of mouth. Such knowledge might enable the Operator
to become fully proactive and adopt a preventive management approach, instead of a retroactive, corrective one.

7. **CONCLUSION: WHOSE REPUTATION SHOULD ONE BUILD?**

Up to this point, the paper has used the term Reputation to address the reputation of the tolled road, as if it were the same as the reputation of the Operator of the road with respect to each specific stakeholder group and stake.

To make full circle and return to the opening argument of this paper, consider two ways to approach trip Safety Reputation. In the first one, the Operator convinces Users that their stake is satisfied because the road is safe (number of accidents etc.). In the second one, the Operator convinces Users that the company’s activities, the various little things that are carried out every day are what keeps the road safe.

The first approach builds the safety Reputation of the tolled road and Users will pay the toll rate to use it. They might as well pay it to the state, or to another Operator, though. The second one builds the Operator’s safety Reputation and Users are willing to pay the Operator to run a safe road. Operators should strategically opt for the second approach.

8. **REFERENCES**


INNOVATIONS IN FINANCING AND PPP IN ROAD PROJECTS

A PRESENTATION BY

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ISTANBUL, TURKEY

SEPTEMBER 15 - 18, 2015
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Builder
Saudi Binladin Group (SBG)
CONTENTS

- TITLE PAGE
- PROJECT PAGE
- CONTENTS
- INTRODUCTION
- PROJECT BACKGROUND
  - Project Description
  - Project Manpower & Equipment
  - Design Management
  - Project Management
  - Construction Management
- OBJECTIVE OF PRESENTATION
- PROPOSED SOLUTION
  - Finance Management
  - Public Private Partnership
- SOLUTION IMPLEMENTATION
- EVALUATION OF RESULTS
- THE PROJECT AND THE FUTURE OF INNOVATIVE FINANCE AND (PPP) IN ROAD PROJECTS
  - Success Of The Project
  - Current Indicators & Future Trends
  - Future Implementation Requirements
  - Conclusions and Recommendations
INTRODUCTION (1/2)

The kingdom of Saudi Arabia has recognized the need for building the strategic road / railroad “Land Bridge” between the Red Sea and the Arabian Gulf, shortening travel time and reducing cost of shipments traditionally carried by water around the Arabian Peninsula. Al Qassim - Al Madinah - Yanbu - Rabigh Expressway represents the first component of this “Land Bridge” (see attached map), and a major step towards completing a comprehensive national network of expressways.

On July 4, 1997, with no public funds available for the total cost of the Expressway, The Kingdom’s Ministry of Communications (now Ministry of Transport), contracted the Saudi Binladin Group (SBG) to design / build / finance the largest single road project in the history of the Kingdom and the Region, and the first design / build / finance contract in this secto.
**INTRODUCTION (2/2)**

- **Land Bridge**
  - "Al Qassim – Al Madinah – Yanbu – Rabigh" Expressway

- **Shipping Route**

  - Length of Land Bridge: 1000 km
  - Length of (Yanbu-Al Qassim) Section: 610 km
  - Length of Main Project:
    - 6-Lane, Divided: 775 km
  - Length of Connectors:
    - 6-Lane, Divided: 20 km
    - 2-Lane, 2-Way: 48 km
  - Total Contract Value: US $ 1.43 Billion
  - Starting Date: January 1, 1998
  - Open to Traffic by January 2005: 610 Km.
    - 80% of Total Work
  - Completed by January 1, 2005: 95%
  - Completion Date: August 5, 2005
PROJECT BACKGROUND (1/8)

Project Description

- **CUT (M3)**
  - Earth Cut (M3)  17 Million
  - Rock Cut (M3)  27 Million
  - Total Cut (M3) 44 Million

- **Fill (M3)**
  - 95 Million

- **Maximum Cuts**
  - Depth 90 Meters

- **Aggregate Base Course**
  - 3.03 Million M3

- **Bituminous Courses**
  - Base Course (M3)  1.91 Million
  - Wearing Course (M3)  1.43 Million
  - Total (M3) 3.34 Million

Caterpillar Dozer D11R

Maximum Cuts

Aggregate Base Course

Bituminous Base Course
PROJECT BACKGROUND (2/8)

Project Description

- Reinforced Concrete
  - 1.31 Million (M3)
  - Interchange (No.) 36
  - Vehicular Crossing (No.) 42

Reinforced Concrete

Interchange
PROJECT BACKGROUND (3/8)

Project Description

- **Wadi Bridge**
  - Number: 19
  - Total Length (M): 4,800

- **Camel Crossing**
  - Total (No.): 11

- **Other Works**
  - Slope Protection: 680,000 M3
  - ROW Fence: 1,620 km
  - Median Fence: 640 km
  - Culvert: 986 km

Wadi Bridge

Camel Crossing

Culverts

Median Fence

Slope Projection
## Project Background (4/8)

### Project Manpower (Number at Peak)
- Engineering & Technical Staff: 302
- Administration: 52
- Equipment Technician: 143
- Equipment Operator: 1,001
- Skilled Labor: 1,851

**Total**: 3,349

### Project Equipment (Number at Peak)
- Dozer (Including 15 CAT D11R): 2
- Loader / Excavator (Including DEMAG H-121): 180
- Truck (Regular): 443
- Truck (High Capacity Including TEREX 33-09): 27
- Motor Grader: 89
- Roller: 215
- Asphalt Batching Plant: 15
- Asphalt Paver (Modified for 16m Wide Spread): 39
- Concrete Central Batching Plant: 19
- Transit Concrete Mixer: 100
- Crusher / Screed: 32
- Other: 310

**Total**: 1,561
PROJECT BACKGROUND (5/8)
Design Management

Design was done by the Builder and its Consultants on a fast-track basis, subject to approval by the Ministry of Transport. The biggest challenge to design was the need to comply with construction schedule and Project budget. In one section more than 33 alignments were investigated.

Special features of Design Management included the following:

- Design / Build / Finance Contract.
- Commencement of Design After Handing Over of Site to Builder.
- Fast-Track & Interactive Integration of Design Activities with Construction Needs & their Financial Impact.
PROJECT BACKGROUND (6/8)

Project Management

- The First Design / Build / Finance Road Contract in The Region.

- A Dedicated Independent Executive High Committee for the Project; a first in Project Management for the Builder.

- On-Site Project Director reported directly to the committee, and fully managed and supervised all Project operations.

- Dedicated Independent Technical / Liaison Office for The Project Stationed at the Builder Headquarter in Jeddah.

- Segmentation of The Project Into Several Major Sub-Projects.

- All works were supervised and certified by the Ministry's Supervision Consultant.
The sheer size of the Project proved to be the biggest management challenge. This has necessitated employment of large number of manpower, procurement and production of huge quantities of materials, and the purchase of high-capacity, high-efficiency equipment and systems. The challenge for optimum utilization of such resources was successfully met, using advanced software, computers and full-range of telecommunication systems.

Special Features of Construction Management included the following:

- The Largest Road-Building Single Contract in The History of the Kingdom.
- Managed by an independent and dedicated Executive High Committee, On-Site Project Director, and Liaison Officer at the Builder Headquarte.
PROJECT BACKGROUND (8/8)
Construction Management (Continued)

- A New and Bold Approach to Road Construction in the Kingdom:
  - Machine-Intensive, High Capacity Pool of Resources.
  - Advanced Technology including GPS in Surveying operations, a first in the Kingdom.

- Results Showed That:
  - GPS Reduced each of Surveying Staff and Time By 65%.
  - High-Capacity Machines Reduced Number of Operators by 50%.
OBJECTIVE OF PRESENTATION

The objective of this presentation is to describe the 775 Kilometer AL QASSIM - AL MADINAH - YANBU - RABIGH EXPRESSWAY Project, and highlight it as a pioneering example in Innovative Financing and Public Private Partnership (PPP) in the transportation sector with the following distinguishing characteristics:

- It is the first full Partnership between the Public and Private sectors where the builder shouldered all Design / Build / Finance responsibilities and delivered a world-class road in the Kingdom of Saudi Arabia.
- It is the first financing by the private sector of a Road Project in the Kingdom and the Region.

The Presentation concludes by highlighting the lessons learned and the applicability, benefits, and requirements of this approach to successful transportation projects in Europe & Central Asia Region, and beyond.
PROPOSED SOLUTION (1/3)

Finance Management

With insufficient Public funds in 1998 to support the Project, the Builder (Saudi Binladin Group) offered to finance the Original Contract (5 years) and its extension (3 years) with following conditions:

- Payment Period 12 Years.
- Project Financed through Zero-Coupon Special Saudi Government Bond Issued by Ministry of Finance, With Builder The Nominee.
- Bonds of Original Contract Mature over 12 Years (Start in 1998).
- Bonds of Additional Works Mature over 8 Years (Start in 2002).

Bonds Conditions:

- Each Bond paid at Maturity.
- Payment Stopped if Cumulative Value of Finished works is less than that of Agreed Project Program.
- A Bond maybe Discounted before Maturity with Prior approval of Ministry of Finance or After Initial Project Handing over.
- No Downpayment to Builder, Hence No Retention From Bonds.
- No Performance Bonds Required from Builder.
- Finance Cost Built Into Project BOQ.
PROPOSED SOLUTION (2/3)
Finance Management (Continued)

General Project Cash Flow

- **Cash Deficit**
- **% Cumulative Value of Executed Work.**
- **% Cumulative Cash In.**
- **End of Original Contract.**
- **End of Modified Contract**

<table>
<thead>
<tr>
<th>Year</th>
<th>1998</th>
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- **Note:** The values are approximate and may require actual data for accuracy.
PROPOSED SOLUTION (3/3)
Public Private Partnership

- In 1997, almost twenty years ago, the Saudi Binladin Group (SBG) took the initiative to propose to the Government of Saudi Arabia its readiness to **design, build and financ**e the largest road project in the history of the Kingdom.

- The Government accepted the proposal; the first time where Public-Private-Partnership was practiced in road projects in the Region.

- It is critical to note that this was not a Toll-Road Proposal, but rather an integrated scheme where **public ownership and operation** of the entire Project remained in the Government’s hands from the Authorization-to-Proceed Stage to the delivery of the completed Project and beyond.
SOLUTION IMPLEMENTATION

The Saudi Binladin Group (SBG) implemented the solution through the following steps:

1. Based on general initial review of the Project with the Ministry of Transport, and on its long experience, SBG estimated the total budget of the Project and its required duration (5 years).

2. The Ministry of Transport and SBG signed a contract based on (1) above, and secured and issued zero-coupon bonds over 12 years to cover the estimated budget.

3. SBG signed an agreement with individual national banks to provide needed funds based on monthly actual performed work.

4. Based on detailed design and Bill-of-Quantities SBG agreed with the Ministry of Transport on a new budget and a new execution period (8 years).

5. The Ministry of Transport secured and issued a separate set of zero-bonds (over 12 years) to cover the increase in the budget.

6. SBG performed its work and issued a certificate of monthly performed work approved by the Ministry. SBG submitted the certificate to the financing bank and got paid.
EVALUATION OF RESULTS

- Without the Builder Initiating full partnership with the Public Sector, and without the financing package, the start of the Project and its benefits would have been delayed for years.
- The single Design / Build / Finance contract elevated the Builder’s risk to unprecedented high level, thus requiring complex risk management of the financing scheme and other project obligations.
- The contract was successfully executed representing a major and pioneering milestone in road building in the Kingdom of Saudi Arabia, the Region, and the World in several major areas including:
  - Strategic Significance.
  - Size.
  - Integration of Design, Construction, and Financing into a Single Contract.
  - Used of Advanced Equipment & Systems.
  - Use of Innovative Construction Methods & Project Management.
  - Risk Management.
  - Success in Contract Management and Delivery.
SUCCESS OF THE PROJECT

The Project was completed in (8) years, opened to traffic, and was accepted by the Ministry. SBG was paid all zero-coupon bonds in (12) years. The project was successful in all technical, management, and financing aspects. In 2005 the Project was awarded two (2) IRF Global Road Achievement Awards (GRAA) in each of the two categories:

1. Innovative Finance; and

2. Construction.

With this it has become the first project in the GRAA history to win two awards in the same year; a solid proof of its success.
In the last three decades a large number of books, research programs, and reports have been published on future and mega trends by well recognized authors and organizations. They were all designed to forecast mega future trends in the world.

Relevant to this presentation, the following current and forecast trends stand out:

- “Public Private Partnerships are set to play a big role in transportation funding” in the USA (1).
- “Driven by new technologies, Nonstate actors take the lead in confronting global challenges” (2).
- As power becomes more diffuse, “a growing number of diverse state and Nonstate actors, as well as substantial actors, such as cities, will play important governance roles” (2).

Above forecasts confirm the emerging need for Public Private Partnership and new governance structure in the world, but adds doubt to their possible success.

(2) Global Trends 2030 (GT-2030), Alternative Worlds, National Intelligence Council (NIC), December 2012.
For any successful PPP and Innovative Financing in the future, and based on SBG success in this Project, the following conditions need to be satisfied:

A. At least three partners must participate as willing and capable partners:
   1. A strong public agency who trusts the private sector to assume the responsibility for design and financing obligations of a public project, typically a public role, and to provide reliable guarantees for the financing partner;
   2. A strong and reliable contractor / builder from the private sector who can deliver a completed project and assumed the risk of the forged partnership; and
   3. A reliable financial institution or institution who can provide needed financial resources for the Project against a reliable guarantee, best from a sovereign entity.

B. The builder / contractor must establish an independent and complete management system for the project.

C. The builder / contractor must use qualified talents, and state-of-the-art construction equipment and technologies.
The success of AL QASSIM-AL MADINAH-YANBU-RIBIGH Expressway in the Kingdom of Saudi Arabia is a pioneering model for future similar undertakings in the Region and the world. Its success has been founded on an effective partnership between the Public and Private Sectors and on Financial Institutions ready to participate and provide needed financial resources.

Effective risk management, flexibility, and clear definition of each partner role has resulted in all winners and no losers.

It is recommended that similar undertakings in the Region, Europe, and West Asia study the presented model and decide on the most effective solution for integrating all available, feasible and willing partners who can deliver needed transportation facilities and services.
ABSTRACT:

Several initiatives have been undertaken for the development of the Euro-Asian transport links and the revitalization of the ancient Silk Road. The International Road Transport Union (IRU), based on its fundamental mission to facilitate road transport worldwide and to ensure its sustainable development, has been activated in one more activity - among several others that are widely known - and presented in 2010 the concept of the “Model Highway Initiative” (MHI).

According to its definition, a Model Highway (MH) is meant to be an exemplary road section with modern ancillary infrastructure and support roadside facilities, designed and built jointly by national governments, international financial institutions, international organizations and the business community, to demonstrate the economic potential of interregional road transportation in the regions of Black Sea, South Caucasus and Central Asia.

In brief, the MHI comprises:

i) international investments in the ancillary road infrastructure (modern petrol stations, motels, safe parking lots, etc.);

ii) harmonized customs procedures in line with international conventions and best practices; and

iii) road transport border crossing points (BCPs) meeting state-of-the-art procedural, infrastructural and technical requirements.

In this framework, and in cooperation with the national governments of the countries concerned, a prefeasibility study for the implementation of the MHI concept on the trans-Caucasian road that connects Trabzon (Turkey - TR), Batumi, Tbilisi (Georgia - GE) and Baku (Azerbaijan - AZ) was elaborated in 2012. Recently, a similar study has been also completed for the extension of the MHI concept across the Caspian in Turkmenistan (TM), from Turkmenbashi Port to the capital Ashgabat.

In this paper are presented the MHI framework as defined and promoted by the IRU, the methodology and activities undertaken for the scope of the studies of the Model Highway trans-Caspian route, from Turkey and through South Caucasus to Ashgabat in Central Asia, and consolidated results of the analyses and conclusions of the two studies.
Model Highway Initiative in Black Sea and Central Asia: towards the development of Euro-Asian Transport Links and the facilitation of international transport and trade

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1 INTRODUCTION

The IRU project “Model Highway Initiative” was first presented in 2010, at the 43rd meeting of the Asian Development Bank (ADB). It found support by major international financial institutions (IFIs) such as the World Bank, the Asian Development Bank, the European Bank for Reconstruction and Development, Black Sea Trade and Development Bank (BSTDB), international organizations such as the Black Sea Economic Cooperation Organization (BSEC), the World Customs Organisation (WCO), the Transport Corridor Europe - Caucasus - Asia Intergovernmental Commission (TRACECA) and eight Eurasian states.

In the framework of the Black Sea Ring Highway (BSRH) cooperation, it was decided in 2012 to investigate the potential for implementation of the Model Highway (MH) concept on the South Caucasian section Baku/AZ - Tbilisi/GE - Batumi/GE - Trabzon/TR (hereinafter the “BTBT MH”). Then, financed by the IRU and the BSTDB, a Prefeasibility Study was elaborated by Egnatia Odos S.A., the BSRH Joint Permanent Technical Secretariat, functioning on the basis of the Memorandum of Understanding (MoU) of the Black Sea Economic Cooperation (BSEC) Organisation (Egnatia Odos S.A., 2012).

More or less at the same time, following the initiatives of the President of Turkmenistan highlighted at his speech at the 66th Session of the United Nations (UN) General Assembly  in 2011 for the development of transit and transport in the Caspian and Black Seas, Central Asia and the Middle East, and after the Resolution of the International Ashgabat Conference “Prospects of Development of Transport and Transit in Central Asia and the Caspian Region” in 2012 and the IRU Amman Declaration and Ministerial Declaration of the 7th IRU Euro-Asian Road Transport Conference in 2013, the Government of Turkmenistan and the IRU signed a MoU “On the creation if the Model Highway in Central Asia and the Caspian Region”. On the basis of this MoU another Prefeasibility Study for the MH development was elaborated, this time for the route between the Turkmenbashi Port and Ashgabat, hereinafter the “TM MH” (Egnatia Odos S.A., 2014).

The aim of this paper is to present the findings of the abovementioned studies, for the potential implementation of the MHI concept, which envisages to become a catalyst for trade and freight traffic increase through the transit states, for the development of small and medium-size business providing services to traffic, and thus for the development of the national economies of the countries involved.

2 METHODOLOGY

2.1 APPROACH AND ACTIVITIES UNDERTAKEN

In order to meet the scope of the MHI, the prefeasibility studies aimed at: a) the registration and assessment of existing physical and operational characteristics of the road infrastructure and ancillary facilities; b) the registration of the conditions and the practices applied at border crossings; c) the evaluation of the international road haulage conditions and the relevant - to transport and investments - legal framework in each country; d) the presentation of best practices for ancillary infrastructure and facilities, the definition of proposed locations and preliminary cost estimation; and e) the examination of the preconditions and potentials for the MH successful implementation, taking into consideration infrastructure development plans, technical and socioeconomic aspects and the competitive routes and transport modes.
The first activity undertaken in both cases was extensive research for data on transport supply and demand, trade, economy, etc. and references for best practices. Studies, reports and online databases of major organizations were used, mainly from the IRU, the UN Economic Commission for Europe (UNECE) and Economic and Social Commission for Asia and the Pacific (UNESCAP), the European Commission Directorate for Mobility and Transport (EC DG MOVE), TRACECA and the Central Asia Regional Economic Cooperation (CAREC). Other data sources comprised studies, Master Plans and documents of the Ministries responsible for transport, infrastructure development and financing of the countries involved.

The definition of data deficiencies due to scarcity, incompatibility and unreliability of available data collected from different sources was followed by expression of official data requests to each of the governmental authorities and the various national agencies concerned, using appropriately designed questionnaires. This second activity for data collection was followed by missions to the transit states, in order to fill data gaps, collect supplementary information from national stakeholders, observe the operation of the existing roads and register the existing ancillary infrastructure facilities along the routes under study.

The missions also aimed at communicating to the various stakeholders the purpose of the MHI and enhance the knowledge of the working team about the particularities and needs of each country. For this purpose, ad hoc interdepartmental coordination groups in charge for all issues related to the MHI implementation were established per country, consisted of representatives from various Ministries, the local representatives of IRU and other national stakeholders. Meetings and structured interviews with the groups were performed in Ankara, Tbilisi, Baku and Ashgabat and with BCPs authorities at all the BCPs along the route, except from Baku Port, which had not been initially foreseen in the BTBT MH study.

2.2 PRINCIPLES FOR THE DEVELOPMENT OF THE ANCILLARY INFRASTRUCTURE

The MHI aims to the upgrading and modernisation of main infrastructure and of the ancillary infrastructure along main road arteries, in order to enhance the attractiveness of international highways for increased cargo haulage and to improve work and rest/leisure conditions for drivers. A MH must ensure:

- Safety against accidents (excluding driver’s misbehaviour), which depends on the road’s features (geometry, pavement, road restraints systems, fencing, etc.) and maintenance. The safest and fastest road category are motorways (or primary highways according to the Asian Highways - AH - classification system), which on the other hand are the most expensive to build, operate and maintain.
- Safety against freight crime (security), which is ensured by patrolling and secured truck parking areas.
- Comfort to road users, which is achieved with rest/service areas and other roadside facilities.
- Minimal time and cost at BCPs, which can be achieved by fighting corruption, by applying state of the art procedures, by using of modern equipment and inspection technologies and by reorganising BCPs.
- Direct access to intermodal transportation systems or inland nodes and services, which is ensured by constructing warehousing and logistics facilities at strategic locations along the route.

Taking into consideration the AGR (European Agreement on International Road Arteries) definition for “Service Facilities”, as road ancillary infrastructure are considered: a) Rest Areas (RAs); b) Service Areas (SAs), including fuel stations, restaurants, etc., c) Truck Parking Areas (TPAs); d) Hotels/ Motels network; e) BCPs and f) Logistic and Freight Centres/ Terminals/ Dry ports, etc. The main characteristics of the three most common ancillary infrastructure categories are:

- RAs: they are physically separated from the motorway carriageways and provide the opportunity to halt in an atmosphere, which affords a distinct change from motorway driving. Usually, they provide water supply, sanitary facilities and waste water drainage.
- SAs: they provide fuel, lubricants and mechanical assistance, rest, refreshment and hygiene facilities, and overnight motel accommodation, shops and tourist services. The combination of services offered depends on the overall plan for the relevant motorway section.
- TPAs: they provide secure parking place and other facilities to heavy goods vehicles (HGVs).

The development of such ancillary infrastructure along the MHs should follow an organized pattern regarding spacing and planning of ancillary infrastructure and the provided services to the road users should be concentrated and of high quality. Such a pattern is described in the Trans-European Motorway Project - TEM (UNECE, 2002) and therefore the relevant specifications were used. Planning and dimensioning should be made for a 20-years horizon and the relevant American Association of State Highway and Transportation Officials - AASHTO methodology was applied (AASHTO, 2001).
3 DESCRIPTION OF THE MODEL HIGHWAY ROUTES - EXISTING AND FUTURE SITUATION

3.1 ROAD INFRASTRUCTURE

The total length of the examined road sections of the trans-Caspian MH is approximately 1.710km, while the maritime connection between Baku and Turkmenbashi is ca. 305km (165 nautical miles). The length corresponds to the existing operational roads, including those that were under construction (e.g. Gandja bypass - AZ) or planned to be constructed on the same alignment. The discrete distances of the two MH Routes, which are presented below, refer to the sections Baku “zero point” to Trabzon Airport and Ashgabat “zero point” to Turkmenbashi Port (as they had been indicated by the governmental officials).

The BTBT MH Route links the cities of Baku with Tbilisi and Trabzon with a total length of approximately 1.135km. It crosses the land strip between the Caspian and the Black Sea through the narrow path between the Greater and the Lesser Caucasus Ranges. However, mountainous sections are limited to 54km in Georgia. Some minor mountainous sections exist also at the Tbilisi bypass and near Batumi. Generally the roads are with low bendiness, except the mountainous sections and those in Turkey, but where a modern highway (2x2 lanes) is in operation. Class I according to the AH classification (UNESCAP, 2003) or superior represent 38% of the total BTBT MH length.

The TM MH Route links Ashgabat with Turkmenbashi Port. It follows an alignment parallel to the Kopetdag Mountain Range from Ashgabat to Balkanabat, where it bypasses the Great Balkan Range towards Turkmenbashi, through a flat and arid terrain. The total length of the existing road is 574km, out of which some parts are 2x3 lanes highway and the rest is a two-lane carriageway, which is being upgraded to 2x3 highway (without emergency lane) in the framework of the highway construction plan that has been effective since 2007. The completed parts of this highway are limited to the Ashgabat - Archman section (130km) and at sections near important towns (Serdar, Balkanabat and Turkmenbashi). Class I according to the AH classification represent 30,7% (176km) of the total TM MH length.

Therefore, at time being Class I or superior roads along the entire MH from Trabzon to Ashgabat is approximately 35,5% of its total length. For the increase of the level of service and safety it is vital to increase this low share of Class I roads and to construct city bypasses to eliminate bottlenecks and minimise accidents risks in city environment. In Azerbaijan, the Gandja bypass has been completed, while in Georgia at Kutaisi and Batumi, in absence of adequate bypasses, heavy traffic is diverted to existing alternative roads. Several projects are on-going or underway for the construction of modern highways: rehabilitation, upgrading and motorway construction projects are on-going or planned in Georgia and Azerbaijan and a totally new closed motorway is to be constructed in Turkmenistan. Thus, by the end of the current decade the road infrastructure along both MH Routes is expected to be substantially improved.

3.2 DEMAND

Demand is a decisive parameter in transport planning and investments, as well as for dimensioning of ancillary infrastructure and overall for the success of the MHI implementation. According to the statistics made available by official sources (reference year 2010), traffic is relatively low (below 10.000veh./day) at most of the sections along the two MH Routes, except at sections in areas near the capitals or main cities.

In Azerbaijan the Average Annual Daily Traffic (AADT) is high near Baku (32.806veh./day to Lokbatan and Alat) with high HGV traffic (21%). Traffic reduces gradually as moving to the Georgian border with AADT of around 10.000veh./day up to Gandja, 6.741vehicles/day up to Kazakh and 2.338veh./day up to Red Bridge (AZ/GE borders). In Georgia the traffic is higher at Tbilisi bypass (18.402veh./day) and on the sections Tbilisi - Gori (11.000veh./day) and Grigoleti - Batumi (11.600veh./day). Traffic at GE/TR borders is around 7.500veh./day and between Rize and Trabzon in Turkey is 15.000veh./day. In Turkmenistan, the highest AADT (5.405veh./day) and lowest HGVs percentage (7,5%) are observed between Ashgabat and Archman. The section of the MH with the second highest traffic is between Gumdag and Balkanabat (AADT 4.044veh./day), but with the highest HGVs percentage (12,8%). The weighted (based on sections’ length) AADT along the TM MH is almost 3.000veh./day and the percentage of HGVs along the entire TM MH is 6,5% (200trucks/day).
Regarding future demand, from the examination of the available forecasts (UNECE, 2011) it is expected that the AADT in Azerbaijan in the period 2015-2020 would be more than 33% of the 2015 traffic, while for a specific section, between Hajigabul and Kyurdamir the traffic will be almost doubled. In Georgia, the forecasts for 2015 and 2020 estimate an increase 28% and by 60%, respectively, while similar increase is expected also on the Turkish part of the MH. Most recent forecasts estimate an increase of traffic by 244% in Azerbaijan by 2030, while for Turkey the increase of AADT expected by 2020 would be by 58%. In Turkmenistan, the traffic forecasts refer to the case of construction of the new Ashgabat - Turkmenbashi closed motorway project, which is estimated to be up to 400%, obviously due to the very low traffic of the base-year of the forecast.

3.3 ANCILLARY INFRASTRUCTURE AND BORDER CROSSING POINTS

The existing road facilities along both routes are insufficient to provide quality services. Along the BTBT MH the existing roadside facilities (fuel stations, caterings, markets, service/ repair shops and hotels) are only sufficient in terms of quantity: there are around 500 roadside facilities - on both sides of the road - in total (222 in Azerbaijan, 225 in Georgia and 62 in Turkey). Most of them are small café/ restaurants and markets (194), located on average at every 2,3km, while the maximum interval between two facilities is 28,7km. On the other hand, roadside facilities in Turkmenistan are very scattered (38 over a length of 574km). No rest or service areas are provided and the intervals between consecutive fuel stations (17 along the route) on some sections are critical, since they vary from 94km to 268km.

Generally, there is no pattern of RAs or SAs along the routes to which a driver can refer. Such a pattern, e.g. providing SAs every 100km, can only be realized in access controlled highways (e.g. section Tbilisi - Gori in Georgia). The existing parking areas at or near BCPs serve as RAs, since the wasted waiting times at the borders are planned by drivers to coincide with their resting times, provided that in each country the driving times do not usually require long stops in the hinterlands.

Ancillary infrastructure development is included in the planning of the countries involved. For example, two modern Service and Rest Centres have been constructed in Georgia, in the framework of an overall plan for the construction of sixteen of such centres along the entire East-West highway at every hour route. Also, in Turkmenistan, where the new motorway Ashgabat - Turkmenbashi is underway, eight RAs, eight SAs, two Major SAs (SA and Hotel/Motel), two TPAs and five Maintenance Centres are foreseen.

Concerning the road BCPs, serious efforts made for their improvement along the BTBT MH. The interventions concerned the physical infrastructure, including installations and equipment, but also the improvement of the practices and methods applied for the controls, in the framework of coordinated plans for Integrated Border Management (IBM). The conditions at BCPs seem good, with no long queues; however this is an artificial image, which is not due to the fast controls (which could be indeed fast in some cases), but due to the existence of parking areas where the transit trucks are concentrated to wait for several hours. An ideal, in terms of operation, BCP has no need for huge parking areas, as a proof of their efficiency. In the end, it is unknown the exact time that a truck driver has to spend in the BCPs. Although the time to cross the borders can be from 5 to 20 minutes, the waiting time in queues or at a parking area could reach a day or so.

At Turkmenbashi Port BCP, the condition of infrastructure, buildings, installations and equipment is generally considered as good or at least satisfactory. Procedural times for trucks are considered relatively low (45minutes on average), for all vehicle categories. No special treatment is provided to tucks under TIR, which represent half of the total trucks’ traffic through the port. Waiting times before the beginning of border procedures are 30 minutes on average, but the main problem are the waiting times during the crossing of the Caspian, which are substantial because the ferry services between Turkmenbashi and Baku are not regular (2 per week), due to the fact that priority is given to wagons transport and the wagons’ loading times are high. This causes delays for trucks crossing the Caspian Sea of ten hours at both connected ports. During NELTI I project (NEA-IRU, 2008) the longest waiting time observed at Turkmenbashi Port was from 1 to 6 days. Haulers reported difficulties in gaining access to ferries, since they are operated mainly for rail freight transport (railway companies are given preference on embarkation). Lack of information about ferry schedules and the limited allocated places for trucks cause queues and delays.
4 PRECONDITIONS FOR THE MODEL HIGHWAY DEVELOPMENT

4.1 COMPETITIVE ROUTES AND MODES - INTERNATIONAL ROAD TRANSPORT FACILITATION

The development potentials of the MHs are directly associated with the evolution of transport supply and demand, but also on other competitive road corridors or other transport modes axes. The comparison of various road routes with origin Ashgabat and destinations Istanbul, Ankara and North Germany proved that the connection of Turkmenistan with Central Europe via the TM MH and Kiev is the most competitive one, ten hours faster than the connection via TM and BTBT MHs and the connection of Ashgabat with Ankara is achieved faster through Iran and the Central and Southern Turkish road network.

However, the Ashgabat connection with Ankara through the Caspian Sea remains competitive, mainly if it combines the two MHs. The same applies for the connection between Ashgabat and Istanbul. Especially after the construction of the new motorway along the entire TM MH route, and given the on-going upgrading plans along the BTBT MH, the route could become even more competitive. Broadly the time savings for trucks along the TM MH motorway would be about 3.5 hours and this would mean that the MHs route could be equally competitive to the Iran - Central Turkey routes to Ankara and Istanbul, under the condition of improvement of the level of Ro-Ro services between Turkmenbashi and Baku.

As regards the competition from Railways, the two MHs have parallel railway axes along their entire length, except from Trabzon (TR) to Poti (GE). Railways could be very competitive to the MHs after the realisation of the several upgrading railway projects in all countries. The Baku - Tbilisi - Kars railway project is envisaged to become the most important railway corridor of TRACECA, while a second competitive rail route is the Istanbul (Haydarpasa) - Tehran (Iran) - (Turkmenistan) - (Uzbekistan) - Tashkent - Almaty (Kazakhstan). Both the rail corridors, originating from Istanbul and Ankara, will increase their competitiveness when the railway upgrading and modernisation of Turkish rail network will be implemented by 2023, including extending the network of High Speed Lines up to Kars. In any case, interoperability issues (track gauge, traction/ voltage) will continue to burden international railway operations with time and cost.

The TRACECA Route Attractiveness Index (TRAX), developed in the framework of “Transport Dialogue and Networks Interoperability” Project (TRT Transporti e Territorio et al., 2011), identified that the nodes are the main obstacles to attract higher freight volumes on transnational routes, in terms of travel and time costs and overall reliability. Especially for the trans-Caucasus route, the ferry crossings of the Caspian and the Black Seas are those affecting its index. National plans for the rational use of the primary infrastructure should be established, to guarantee fair competition between transport modes and ensure an integrated transport and logistics system, providing at the same time advanced and non-discriminatory access of road hauliers to improved ferry services.

Therefore, apart from the projects that have been or are being implemented/planned to modernise the road infrastructure, there are other projects and measures to be implemented in order to meet the needs of international transport demand, at critical nodes along the MH. This is translated to projects for radical reconstruction and improvement of BCPs and developments at Ports and ILCs. Road BCPs have been reconstructed (Sarpi - GE and Red Bridge GE and AZ) and have modern and clear installations, new equipment and buildings. This provides appropriate working conditions to the staff, hospitality and clarity to the users, which are preconditions for better border operations and advanced BCP management.

The better service of the increasing flows can be achieved through the expansion of physical infrastructure (where possible), combined with intensive cooperation between the responsible authorities of the two pairs of BCPs and ideally in later stage to perform controls jointly or establish joint stations. In the meantime, the cooperation for exchange of data (a project has been commonly undertaken by the BTBT transit states for Electronic Data Interchange), the improvement of performance of staff and the application of most appropriate best practices (according to the particularities of each country and BCP) would help the reduction of border crossing times, and especially the waiting times before border procedures.

Above all, in order to facilitate border crossings, the countries should take actions on the basis of International Conventions and Agreements or other cooperation agreements signed at bilateral or regional level. Especially Turkmenistan should access the ECO (Economic Cooperation Organisation) multilateral permit system and several other relevant Conventions and Agreements. All countries should apply the
provisions of the International Convention on the Harmonization of Frontier Controls of Goods and especially those with reference to the procedures for international road transport for inspections, advanced information exchange and mutual recognition of the International Vehicle Weight Certificate. Introduction of special lanes for trucks under TIR (Transports Internationaux Routiers Convention) at BCPs, application of TIR-EPD (Electronic Pre-Declaration) and single window concept implementation are measures that would improve border operations. To this end, the necessary measures and institutional reforms for international road transport facilitation are presented in country-based Road Maps in NELTI 2 project (NEA-IRU, 2011).

4.2 INTERCONNECTION WITH INTERNATIONAL PROGRAMMES, INITIATIVES AND POLICIES

The two MH Routes constitute the backbone of the national networks and basic content of the transport strategic programs of the countries involved. They are also included in initiatives of various international organisations and institutions for the development of major infrastructures, transport and trade in Europe, Caucasus and Asia, providing thus a sound basis for the promotion of the MH.

Specifically, both routes are included in the International E-Road network of the UNECE (E-70 from Trabzon to Poti and E-60 from Poti to Baku and from Turkmenbashi to Ashgabat) and the UNESCAP AH project (AH5). Their importance is verified by their inclusion in the joint UNECE/UNESCAP European-Asian Transport Links (EATL) project’s Road routes 4e (Trabzon-Batumi), 4 (Poti/Batumi-Tbilisi-Alyat-Baku) and 4f/6g (Baku-Turkmenbashi-Ashgabat). Additionally, both routes constitute parts of TRACECA: Trabzon - Batumi (Route 18), Batumi/Poti - Tbilisi (Route 20), Tbilisi - Baku (Route 22) and Turkmenbashi - Ashgabat (Route 24). Part of BTBT MH in Azerbaijan and the TM MH are included in the Mediterranean - East Asia Corridor (No 2 and 2b), one of the six CAREC Multimodal Corridors (ADB, 2008).

Furthermore, the BTBT Route is included in the EC DG MOVE planning of European Transport Axes, linking European Union (EU) with neighbouring countries and regions. The “Networks for Peace and Development” Report, officialised by the EC in 2007 in the framework of the “European Neighbourhood Policy” strategy (ENP), defined the BTBT Route as part of the South Eastern Priority Transport Axis, while the TM Route is in the physical extension of this Axis (through Baku Port) as well as of the Central and the Inland Waterways Priority Transport Axes Don/ Volga (through Astrakhan Port). The new “Neighbourhood Transport Action Plan” of the ENP aims to strengthen transport links of EU with neighbouring regions and in 2013, after the Joint Declaration “Future of Eastern Partnership transport cooperation” of the EU and the concerned countries in Eastern Europe and Caucasus, the “Eastern Partnership Transport Network” has been defined, with the Trans-European Transport Networks (TEN-T) extensions in these countries. Part of this network is the multimodal Caucasian axis from Batumi and Poti to Baku, in extension of the Comprehensive TEN-T in Turkey, as indicatively presented in the TEN-T EU Regulation (European Union, 2013).

4.3 ROADSIDE FACILITIES PLANNING AND FINANCING

The development of ancillary infrastructure along the MHs should include: i) expansion of the network of fuel stations; ii) creation of a parking facilities network, which would provide convenient and safe parking for international haulage vehicles, technical maintenance facilities and retail outlets for spare parts and convenience goods; and iii) expansion of a network of hotels and motels to cover drivers’ rest periods.

Each transit country has to be evaluated separately, taking into account the existing situation and the national planning and development plans, including important nodes. Such nodes are Baku, Alat and Red Bridge BCP in Azerbaijan, the Red Bridge BCP, Tbilisi, the Sarpi BCP (or Batumi) and Kutaisi (considered as possible International Logistic Centre - ILC) in Georgia, the Sarp BCP in Turkey and Ashgabat, Archman, Gumdaq/ Balkanabat and the Turkmenbashi ILC (which is under development in the framework of Turkmenbashi Port expansion project) in Turkmenistan. Then a more detailed plan for development of ancillary installations along the MH should be elaborated, in order to specify the locations and type of ancillary infrastructure and the terms for their development (land acquisition, design, cost, environmental aspects, etc.). This plan should be assessed within a Feasibility Study, which should make an advanced assessment of the market potentials based on corridor and logistic chain analysis, examining in detail parameters such as the origins and destinations and the type of commodities transported. However, despite the status of development of the main road infrastructure which will be ongoing for several years from now, the provision of facilities according to the international standards and certainly constructing RAs and fuel stations at regular spacing should be considered urgently (especially in Turkmenistan).
The roadside facilities required along the two MH Routes, 123 in total (12 in Turkey, 27 in Georgia, 42 in Azerbaijan and 42 in Turkmenistan), were defined by applying the principles and specifications for ancillary infrastructure development mentioned in Section 2.2 of this paper, exploiting the existing traffic forecasts and making the appropriate extrapolations for time-horizon extension or for using more realistic forecasts, where only “low” and “high” demand scenarios existed. The cost estimations, excluding the ILCs and BCPs costs, were €138million for the BTBT MH and €73million along the TM MH, i.e. 211mo€ in total.

In the case of the BTBT MH, the establishment of a Regional Infrastructure Fund (RIF) was identified as an effective coordination mechanism for the accumulation of financial resources of the various investors, their allocation to particular projects for ancillary infrastructure development, the coordination of construction works and operation of the MH with the national governments, international organisations, IFIs and business, and for managing the operation of the constructed roadside services’ assets through managing operating companies (IPDG, 2012). The RIF establishment and operation wouldn’t be an additional burden for the national governments, which would contribute with official support to the MH development, provision of state guarantees on infrastructure investments, simplification of land allocation procedures and establishment of favourable tax regime for business developing ancillary infrastructure services.

As regards the involvement of foreign investors in road and roadside infrastructure development projects, it follows the pattern of involvement in doing other sectors businesses, which during the last years has become quite common. Especially regarding Public Private Partnerships (PPPs), even though relevant legislations are pending, the involvement of the private sector has not been hampered in other cases, like in energy, airport and motorway projects. However, further reforms are requested, in order to ensure a solid, clear and transparent legal basis for PPPs. Actions to remedy the various shortfalls under existing laws that currently make PPPs unattractive must be taken, such as provision of more flexibility during concession contracts negotiations and availability of more security instruments in favour of lenders.

4.4 EXPECTED IMPACTS

The improvement of the level of service along the MHs should comprise improvements of the main road infrastructure, of the ancillary installations and BCPs and of the connections to major trip generators and attractors, both for passengers and freight. The improvement of the main road infrastructure - traditionally a growth engine along its alignment - directly provides vehicle operating cost savings, accidents reduction, time and cost savings for passengers and freight. Other benefits expected concern increase of international traffic and trade, of employment and productivity, regional development and territorial convergence, increased accessibility and mobility of people and higher living standards.

More reliable road transport services will ensure efficient movement of freight and passengers across the borders, better access of local communities to markets and social services and job and income opportunities created during project implementation (i.e. use of local labour and construction materials) and after project completion (i.e. roadside businesses). Also benefits for the tourism industry and the cultural exchanges are expected from the increased accessibility of the regions.

Environmental benefits are also expected, for example from the construction of city bypasses, but of course all types of improvements should be subject of full Environmental Impact Assessment studies and Resettlement Plans. On the other hand, closed access motorways, city bypasses and more organised roadside complexes could endanger local small scale businesses along the existing road. Therefore, there should be provision for special conditions of cooperation of new ancillary infrastructures, in the form of incorporation of the local businesses in new centres (resettlement, privileged rents etc.). Already, such a provision is applied at the new roadside service stations constructed in Georgia, where apart from fuel stations they include supermarkets, farmers’ markets and spaces for exhibition of local arts and crafts.

5 CONCLUSIONS

The analysis performed verifies that despite the progressive development of main road infrastructure, this is not accompanied with development of roadside facilities. The quality of provided services along the two MH Routes examined through ancillary infrastructure is admissibly low, with very few exceptions.
The importance of the two MH Routes, which are the backbone road network in the countries involved, but at the same time are part of the international strategic networks, provide a framework of strong political will and commitment for large scale investments, through national budgets and the participation of the IFIs. This commitment is materialised through the on-going and underway projects of motorway construction and upgrading, which will ensure modernised, safe and efficient road infrastructure to the users in the future.

The development of ancillary roadside infrastructure assets should be also ensured, as promoted by the MHI. Both components of the MH (main roads and roadside facilities) have to be financially viable and thus able to attract the necessary funds from IFIs and private investors. This highlights the importance of ensuring adequate traffic volumes along the MHs, which can only be achieved through the implementation of legal and administrative reforms and effective measures aimed at the facilitation of international road transportation of cargo and at the improvement and harmonisation of the border crossing operations and procedures along the entire MH, including those performed at the Caspian Ports. In this aspect, not only procedures should be effective, but ferry services between Azerbaijan and Turkmenistan should become non-discriminative, regular and reliable for road transport, in order to increase as possible the competitiveness of the entire route and provide the possibility to be an efficient alternative to other main alternative road (and not only) Euro-Asian Corridors. In any case, the success of the MH implementation goes in hand with the support of the national governments, the international cooperation and coordination.

6 ACKNOWLEDGEMENTS

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Transport Corridor Development in Developing and Frontier Markets: Operational techniques from Afghanistan to increase economic rates of return for infrastructure investments in major road construction projects.

PAPER TITLE

Transport Corridor Development in Developing and Frontier Markets: Operational techniques from Afghanistan to increase economic rates of return for infrastructure investments in major road construction projects.

KEYWORDS:
Transport Corridor Development; Capacity Building; Investment: Economic Rate of Return

ABSTRACT:
Transport corridor projects are strategic investments in major engineering and construction works with the objective to boost regional economic growth and political-social stability. For transport corridor projects in developing and frontier markets, and particularly in rural areas, the construction demand often exceeds what local industrial capacity can ordinarily supply. This surge of construction economy provides a unique opportunity for underdeveloped and rural communities to leverage resources to scale infrastructure development in the transport corridor. A comprehensive investment strategy can maximize the civil return on the civil engineering input-output traditionally applied on a transport corridor project.

This presentation intends to analyze the economic, social, and political impacts of recent transport corridor projects in Afghanistan. It will use data gathered over the course of the project delivery, including quantitative data collected using several survey instruments (vehicle operator, household, small business) as well as qualitative data gathered in various focus groups and key informant interviews. It will use several metrics to measure road impact, including traffic volume, travel time, vehicle operator costs, costs of freight transport, passenger fare costs, cost of informal payments, cost of food staples, and access to health care. This paper will offer insight into how quickly one such road, the Keshim – Faizabad Road, yielded immediate social and economic impacts.

In addition and perhaps more importantly to civil engineers and project managers, this paper will make recommendations on project implementation techniques as to how to operationalize road investments for sustainable capacity building. It will make recommendations on incorporating social and economic outputs (e.g., local employment, technology transfer, local trade) into civil engineering planning and utilizing monitoring and evaluation during the project implementation phase (e.g., active community engagement, strengthening governance, safety education). It will also argue for the adoption of a transport corridor approach to road development, which broadens the scope of road projects to include a spectrum of complementary initiatives, such as the construction of feeder roads, value chain development, vocational training, and the provision of basic village infrastructure. These initiatives would focus on accelerating the benefits of a road investment by helping local communities take advantage of local economic growth opportunities during road construction as well as the new access a road brings to markets and social services.
Introduction

For 30 years, the people of Badakhshan Province—the most northerly, mountainous, and remote of Afghanistan’s 30 provinces—have fiercely fought, first the Soviets and then the Taliban. However, infrastructure in the region has been lacking. Commencing in June 2006 with field investigation and design activity, the Government of the Islamic Republic of Afghanistan and The United States Agency for Relief and Development (USAID) successfully completed reconstruction activities for a $125 million road reconstruction project in December 2010.

The existing dirt and gravel road that connected the provincial capital of Faizabad to the national Rign Road via Keshim, a small town to the west, was so badly eroded by the elements that the 103-kilometer trip by car became dangerous and took an entire day. Trade between Faizabad and Keshim was minimal, the cost of goods exorbitant, and medical care almost non-existent. Though geographically isolated, Keshim is strategically important, serving as a critical link to Kunduz, the Ring Road and other regions of Afghanistan and Central Asia. The United States Agency for International Development (USAID) committed to building the Keshim-Faizabad road which links this isolated provincial capital to the National Highway system as part of the Bonn Process’ Afghanistan Compact, the London Conference’s Afghanistan National Development Strategy and ratified by former President Karzai and the Government of Afghanistan.

Tackling a roadway that paralleled a raging river and wound through two mountain ranges, engineers designed a new road, incorporating the use of locally available materials and skills. Engineers also built a temporary roadway to maintain a passageway for those who needed to travel along the alignment during construction. In order to widen the existing road to accommodate two-way, two-lane traffic, engineers determined that it needed to remove 100-meter-high rock walls to create a sufficiently wide carriageway. The team cut and blasted 3 million cubic meters of rock and common excavation. In total, more than 1,300 controlled blasts were necessary for the rock excavation—a feat that required coordinating not only with the Afghan government and USAID, but with the International Security Assistance Forces as well.

Figure 1 – Controlled blasting operations were required to widen the roadway template to support two-lane traffic on the Keshim to Faizabad Road, Badakhshan Province, Afghanistan

The project team literally moved mountains to open the asphalt road in October 2010 before the first snowfall. The KF Road now features a two-lane, full-depth, asphalt-concrete road, with a seven-meter wide carriageway and paved shoulders built to AASHTO and FHWA standards. The asphalt riding surface combined with a new profile and grade alignment greatly increased mobility in the corridor with a 50% reduction in travel time resulting in traffic demand increases from 565 to 1,614 vehicles per day. The USAID road investment also yielded positive value added economic rates of return with passenger fares decreasing...
by 59 percent, freight costs decreasing by 400 percent, and access to health care increasing 12 percent. In addition, the project trained 177 Afghans engineers and construction administrators, employed 2,659 Afghans, and incorporated numerous local Afghan contractors and vendors to support private sector development.

Figure 2 – Former Afghanistan President Karzai visits with engineers building the Keshim to Faizabad Road, Badakshan, Afghanistan

From a project specific viewpoint, the KF Road was a success; but does it provide us with a benchmark to plan future transport infrastructure development projects at the regional or even global context? More directly, what can we learn from the reconstruction efforts in Afghanistan about how to operationalize strategic investments in infrastructure development such as major roads and transport corridors. This paper looks at some of the lessons learned during implementation that we in the road building community can incorporate in our project design to increase or at least optimize economic rates of return on the limited capital available for investment in transport infrastructure.

Background

The Keshim to Faizabad Road is a 103 kilometer road in the Hindu Kush Mountains of northern Afghanistan which connects the district center of Keshim to the provincial capital city Faizabad thus strategically connecting Badakshan province to Afghanistan’s national Ring Road. The newly reconstructed road provides almost 700,000 residents and businesses with a reliable, safe, all season, all weather transport facility that replaces an ancient dirt and gravel trace renowned for congestion, disruptions, and horrific traffic accidents in the mountainous terrain.

In 2006, USAID through a grant from the United Nations Office for Project Services (UNOPS) tasked their Afghanistan Infrastructure Reconstruction Program implementing consultant, The Louis Berger Group (LBG), Morristown, New Jersey, United States, to design and construct a new two-lane, all weather, asphalt road. LBG prepared a modern highway design with nine bridges and over 600 drainage structures in accordance with U.S. AASHTO standards. In 2007, LBG awarded a construction services subcontract to the Samwhan Corporation, Seoul, Korea, to provide the plant, equipment, labor and materials to build the road. Given the limited construction capacity in the local and national market, LBG and Samwhan planned, hired, trained, and financed a local construction industry which not only supported the immediate construction needs, but provided an accelerated economic boost and capacity gain in Afghanistan’s construction industry. In 2010, a team of transport economists from LBG conducted field interviews and surveys then prepared an
economic study and assessment of the capital investment. The findings were generally positive with reduced travel times, increased commercial truck traffic counts, reduction in passenger fares and freight costs.

**Discussion: Economic return on investment**

As with most economic rate of return (ERR) determinations, the ERR for the reconstruction of the Keshim to Faizabad Road is subjective and certainly arguable on causality between the relationship between the road reconstruction investment and recent growth in economic activity. However, the anecdotal evidence does present a strong case that a $190.62 investment per capita resulted in a high rate of economic return on invested capital. A summary of the findings presented by the LBG transport economists in the USAID Afghanistan Infrastructure and Rehabilitation Program Keshim-Faizabad Road Socio-Economic Post Project follows:

- Car traffic volume increased by 22 fold and two-axle truck traffic increased by 57 percent
- Travel times for the average passenger decreased by 75-80 percent
- Passenger fares decreased by 59 percent
- Freight costs decreased by 36 percent and average freight loads increased from 16 to 19 tons
- Daily freight volume increased by 24 percent
- 12 percent more people are making trips to health facilities
- Greater convergence in food commodities sold in Keshim and Faizabad markets

The study team utilized household surveys, business and market surveys, village elder surveys, and various vehicle operator surveys. ERR was proxied generally by seven economic indicators:

- Traffic volume
- Travel time
- Passenger fare costs
- Cost of freight transport
- Markets where goods sold
- Cost of food staples
- Access to health care

These economic indicators were nested within a higher framework at the strategic or national level in order to provide a methodology for performance monitoring and evaluation of the USAID infrastructure investment.
Figure 4 – Strategic objectives with supporting economic indicators used by the LBG Study Team to measure performance of the USAID infrastructure investment in the Keshim to Faizabad Road, Badakshan Province, Afghanistan

The performance monitoring and evaluation framework was key to building a solid baseline and comparative data to determine an ERR and assess the infrastructure investment. A detailed discussion by the LBG Study Team can be found in their Post-Project Report referenced below. The key in this paper is to highlight to future project implementers and project managers, typically engineers, that economists and supporting tasks such as monitoring and evaluation must begin their work early in the project lifecycle if not at the onset of project kickoff to ensure the overall economic, social, and financial objectives are achieved.

Conclusion: Operational techniques for engineers and construction managers to optimize ERR

For civil engineers and construction managers, it is important to appreciate and understand the greater context on why large capital investments are made in road construction projects. It is more than just connecting dots on a map and ensuring technical standards are met and project compliance adheres to the triple constraints of quality, time, and cost. Given contemporary constraints in the availability of infrastructure finance, recognizing the need to achieve a positive ERR is a good start. However, real value added is finding opportunities to increase ERR during project implementation, or in effect operationalizing transport infrastructure investments to accelerate local economic development and growth.

Based on the feedback and experience building roads in Afghanistan, such as the Keshim to Faizabad Road, four lessons learned are offered for consideration to operationalize strategic road investments:

Operational Technique #1: Assess and incorporate local materials and construction resources during the design process to maximize local participation.

In 2006, the Afghanistan Investment Support Agency (AISA) had over 1,000 local Afghan companies registered in the Afghanistan construction industry. However, a prequalification process which included an
Afghan Road Builders Conference to gauge real capacity in the construction industry indicated only a few of those firms had the financial capacity to manage a million dollar construction project let alone the $100M plus KF Road contract; and no firm with the technical experience to build the KF Road to international standards (AASHTO). For the KF Road reconstruction project, the decision to engage international general contractors to perform the construction services was the most risk adverse course of action. This decision bore the criticisms of a populist lament to award construction contracts to local companies notwithstanding many of such critics did not have the experience or background to truly understand the project dynamics. Local construction companies were just not ready technically nor financially to deliver the works. That said, a very robust subcontracting procurement strategy was implemented which did support local contracting while at the same time supporting technology transfer between the general contractor and the various local Afghan subcontractors. For example, due to the dangerous conditions of operating heavy machinery in the mountain section of the KF Road, Samwhan Corporation conducted the rough excavation until the benches and templates were wide enough to safely task local companies to complete the works. Other examples included fine grading and steel beam slip-critical bridge connections where international tradesmen led local Afghan crews resulting in an on-the-job training and skills development during construction. As a result, this local subcontracting strategy provided a safe and effective capacity building venue for local construction companies to learn technical practices from experienced engineers while increasing their financial capacity with a steady source of cash flow and working capital.

Figure 5 – Local Afghan construction workers building concrete causeway on the Kandahar to Herat Road in Afghanistan

Operational Technique #2: Utilize local hiring practices and subcontract procurement policies that support a strategic interest to improve local construction capacity.

Like most of the recently built and reconstructed roads in Afghanistan, the KF Road surface utilized hot-mixed asphalt concrete pavement for the base course and wearing course. Considerable experience and quality control are required to build an asphalt road, particularly when using specialized mix designs such as polymer-modified bitumen. Further, any successful paving program requires a mature construction industry complete with a requisite supply of quarries, crushed aggregate facilities, asphalt batch plants, and paving contractors. Not only is this construction industry capacity needed to build roads, but also to maintain them. Such considerations must be considered by infrastructure planners and project managers to ensure due participation of local industry in the construction delivery of a major road construction project. This will ensure a ready supply of capacity is available to maintain the road in the future while also providing industrial capacity to build feeder roads to further economic growth.
Operational Technique #3: Accelerate economic growth in the construction industry with formal capacity building of local engineers, tradesmen, and supporting businesses.

A formal capacity building strategy improves upon informal technology transfer resulting from on-job-training and local subcontractor hiring. Ideally, a formal training program is designed to ensure individual skills are developed that support a greater collective capacity, i.e. a crew or task capacity. For example, asphalt paving as a collective construction task requires placement, compaction, testing, batching, crushed aggregate production, quarry operations, trucking, and maintenance operations. Each of these collective tasks are further broken down into sub-element tasks to the individual level. Then, a formal training plan can
be developed that assigns and tracks local participation and performance, at the individual level, leading to an overall collective task capacity.

Capacity building in project overhead tasks such as project management, quality control, and finance should also be considered. For example, rapid gains were evidenced in construction skill development by local Afghan workers and subcontractors. However, constraints remained on their growth potential due to limited experience in project scheduling, construction coordination, procurement, and quality control. Even greater was the growth constraint due to limited working capital and access to finance in an inefficient local banking market. Project planners and project managers should consider using tools such as partnering, guarantees, and direct payments to directly engage with local contractors and subcontractors to help match financial capacity to operational capacity.

Operational Technique #4: Measure the economic impact, assess it, and then repeat.

One of the constraints with the KF Road Post-Project Report was the baseline study was performed at the mid-point of the construction process. At that time in the project schedule, a significant amount of rough grading had been accomplished supporting two-way traffic in the mountain zone, a first for this route. Additionally, several kilometers of roadway fine grading, crushed aggregate paving, and some limited asphalt paving in urban areas had been accomplished which was already yielding economic improvements before baseline surveys could be accomplished. The lesson learned here is to establish a pre-construction economic baseline no later than during the design phase of the project. Then, conduct periodic impact assessments through construction with a final post-construction survey to capstone the data to assess the project’s ERR.

Summary

The Keshim to Faizabad Road construction project in Afghanistan yielded positive economic rates of return on several socio-economic indicators ranging from reduced travel times and vehicle operator costs to consumer good prices and infant mortality rates. As such, from a strategic investment viewpoint, the KF Road was a successful investment, but the question remains if it was an optimized investment from a construction capacity level? True, as with many recent construction projects in Afghanistan, local capacity building transpired through local hiring, training, and subcontracting opportunities. Yet, there is room for improvement in future investments in projects like the KF Road. Large strategic investments in major road transport corridors are infrequent so planning to leverage such capital calls for project planners and project managers to operationalize the investment using techniques to build local construction industrial capacity during this limited time of market growth.

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# Simulation Modeling of Traffic Impact Analysis with GIS Integration

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## KEYWORDS:
Traffic Forecast; Traffic Assessment; System Dynamics; Simulation Modeling of TIA; Land use in remote sensing with GIS

## ABSTRACT:
Traffic Impact Analysis (TIA) is a study to assess the adequacy of the existing or future transportation infrastructure to accommodate additional trips generated by a proposed development, redevelopment or land rezoning. TIA is a powerful tool for engineers and planners to determine the possible effects of a project on the transportation and traffic system. It is one of the important tools in assisting public agencies while making land use planning decisions especially for managing traffic in planning their respective transportation systems. Most of the cities have less than 20% of area under transport land use as against 30% or more of land area in many cities of developing countries. Chennai metropolitan is not an exception in India with regard to its extent land use allocation for transportation purpose. Rajiv Gandhi Salai or Old Mahabalipuran Road (OMR) /Information Technology (IT) Corridor is one of the major roads in Chennai and it has the potential to become a world-class facility in the State of Tamil Nadu. Since the corridor is characterized by a continuous growth in population with rapid urbanisation, mushrooming of IT/ITES related companies. This has led to the increase in vehicular ownership, leading to problems like congestion, road accidents and environmental degradation along the corridor. Conventional models do no exhibit wide range of policy and scenario analysis while assessing the traffic impacts due to the land use/urban development. Hence, it is imperative to study in depth the interaction between land use and transport with respect of traffic impacts by applying Systems Dynamics (SD) modeling approach. The major objective of the research work is to study and assess the prevailing situation for vital traffic parameters and land use disposition using Remote Sensing technology and to build a micro-level SD model using STELLA simulation software that would forecast service level. Prediction of future land use disposition in the year 2026 by various scenario analyses is also carried out. The study infers that TIA is one of the environmental impact assessments which must be addressed in any environmental impact report. Since it checks the adequacy of the land use development with respect to its traffic component and both the land use and transport system should always go in a symbiotic manner, TIA should be conducted in a mandatory way and must be certified by the concern authority as well before issuing any building development permit.
Simulation Modeling of Traffic Impact Analysis with GIS Integration

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1 INTRODUCTION

Traffic Impact Analysis (TIA) is a powerful tool for engineers and planners to determine the possible effects of a project on the transportation and traffic system. Often, it is applied only to the direct impact area and counter measures for potential negative impacts are specific for the development. These studies vary in their range of details and complexity depending on the type, size and location of the development. All development generates traffic, and it may generate enough traffic to create congestion and to compel the community to invest more capital into the transportation network, whether it is in the form of new roads or traffic signals or turn lanes. Traffic congestion results in a number of problems, including economic cost due to delayed travel times, air pollution and accidents. As one roadway becomes congested, drivers may use other roadway not necessarily intended for through traffic. As a result, traffic impact analyses are becoming more common as a planning tool to predict demands on the transportation network. Hence, TIA is considered important as budgets for public facility and infrastructure improvement become strained. Such studies can be used to help evaluate whether the development is appropriate for a site and type of transportation improvements required in order to maintain a satisfactory level of service.

2 SIGNIFICANCE OF TRAFFIC IMPACT ANALYSIS (TIA)

The key potential and importance of TIA is to:
- Forecast additional traffic associated with new development, based on accepted practices
- Determine the improvements that are necessary to accommodate the new development
- Assist communities in land use decision-making
- Identify potential problems with proposed development which may influence the developer’s decision to pursue it
- Allow the community to assess the impacts that a proposed development may have
- Help to ensure safe and reasonable traffic conditions on streets after the development is complete
- Reduce the negative impacts created by developments by helping to ensure that the transportation network can accommodate the development
- Provide direction to community decision-makers and developers of expected impacts
- Protect the substantial community investment in the street system

3 OBJECTIVES OF THE STUDY

- To study and assess the prevailing situation for vital traffic parameters and land use disposition using Remote Sensing technology.
- To build a micro level System Dynamics (SD) model for Chennai IT Corridor, which project service level and future land use disposition by various scenario analysis.
- To assess traffic impacts of the present and future developments along the study area.
- To recommend the necessary counter measures to enhance the Level of Service (LOS).

4 STUDY AREA

Chennai has become one of the preferred destinations for IT/ITES companies. Tamil Nadu, India is the second largest software exporter in the country, and 90% of the export is from Chennai alone. A large number of IT/ITES developments are happening along the Old Mahabalipuram Road (OMR). The study area selected (as shown in Figure 1) is now called ‘Rajiv Gandhi Salai’ or IT Corridor, the road earlier called as OMR. OMR or IT Corridor is a major road in suburban Chennai, India, beginning at the Madhya Kailash temple in Adyar in South Chennai and continuing south till Mahabalipuram in Kanchipuram district, ultimately merging with the East Coast Road. This is popularly called as the “IT Corridor” because this stretch has become home to many IT/ITES companies. Figure 1 depicts the index map of the study corridor (Red colour boxed region encompassing IT Corridor). The IT Corridor Project is an
initiative of Government of Tamil Nadu to develop the Corridor as a world-class facility and to promote a progressive IT/ITES friendly image of Tamil Nadu. The entire stretch is built as 6 lane road and the IT expressway is in operation since October 2008.

Figure 1. Index map of study corridor

IT Corridor is characterized by a continuous growth in population and area of urbanization, a proliferation of IT/ITES companies, industrial, commercial centers, institutional, an increase in vehicular ownership, all of which have created problems like congestion, road accidents and environmental degradation. Hence, it is imperative to conduct a Traffic Impact Analysis (TIA) for this corridor in order to enhance the future LOS within tolerable limits.

5 SOFTWARE USED

A preliminary visual interpretation of the base maps was carried out. ArcGIS 10.1 was used to digitize land use maps and edited in Arc Tool Box in GIS environment. After digitizing the study area, different themes like residential, commercial, institutional, industrial (all polygon themes) and the corresponding landuse were digitized from the land use data obtained from the remote sensing satellite image. The road theme has been created to indicate the location of the road in the region. The land use themes have been created to represent the type of land uses in and around the road corridor.

The model of traffic impact analysis using the System Dynamics (SD) has been implemented in the ‘STELLA’ environment using STELLA 9.1. The modeling tool which is an object-oriented simulation environment allows the development of TIA models with significantly less effort than traditional programming languages. It has a user-friendly graphical interface and supports modular program development. Using this tool, the modeler defines objects representing physical or conceptual system components and indicates the functional relationships among these objects. Building on these strengths, the general architecture of a TIA model will be described (Umadevi,G, 2009).
6 METHODOLOGY

The methodology is a usage of simplified methods or techniques adopted for achieving the formulated objective. The methodology of this work is depicted in Figure 2. Essentially, the steps involved are data collection, analysis, model building and to suggest appropriate mitigation measures.

![Figure 2. Flowchart depicting the methodology adopted in the study area](image)

7 DATA COLLECTION AND ANALYSIS

The collection of data is necessary to assist in the crystallization of facts and figures, the interpretation of which will lead to more realistic analysis of the land use pattern, traffic and travel characteristics of the study area, which thereby helps in the formulation of mitigation measures against negative traffic impacts and spatial developments of along the corridor.

7.1 Classified Traffic Volume Count Surveys (CTVCS)

One of the major components of the transportation inventory is the volume count of traffic on the study corridor during peak hours on a typical working day. The classified traffic volume counts are conducted manually by counting vehicles on both directions at two selected locations of the study corridor for five hours. The volume data has been converted into Passenger Car Unit (PCUs) by utilizing recommended PCUs factors as specified in IRC: 106-1990. The first location is near Indira nagar railway station; the second location is Karapakkam, near Apollo Hospital.
Table 1. Traffic Flow along the Chennai IT Corridor

<table>
<thead>
<tr>
<th>Time</th>
<th>Car/Jeep</th>
<th>Auto</th>
<th>Two Wheeler</th>
<th>Bus</th>
<th>HCV</th>
<th>LCV</th>
<th>Cycle</th>
<th>Other</th>
<th>Total (Nos)</th>
<th>Total (PCU’s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3:30-3:45</td>
<td>355</td>
<td>37</td>
<td>477</td>
<td>65</td>
<td>9</td>
<td>55</td>
<td>10</td>
<td>3</td>
<td>1008</td>
<td>1008</td>
</tr>
<tr>
<td>3:45-4:00</td>
<td>424</td>
<td>39</td>
<td>558</td>
<td>58</td>
<td>6</td>
<td>50</td>
<td>5</td>
<td>2</td>
<td>1159</td>
<td>1150</td>
</tr>
<tr>
<td>4:00-4:15</td>
<td>496</td>
<td>49</td>
<td>611</td>
<td>85</td>
<td>10</td>
<td>63</td>
<td>11</td>
<td>4</td>
<td>1326</td>
<td>1325</td>
</tr>
<tr>
<td>4:15-4:30</td>
<td>543</td>
<td>37</td>
<td>647</td>
<td>61</td>
<td>14</td>
<td>64</td>
<td>10</td>
<td>2</td>
<td>1376</td>
<td>1337</td>
</tr>
<tr>
<td>4:30-4:45</td>
<td>478</td>
<td>40</td>
<td>689</td>
<td>72</td>
<td>15</td>
<td>60</td>
<td>6</td>
<td>3</td>
<td>1362</td>
<td>1328</td>
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<tr>
<td>4:45-5:00</td>
<td>458</td>
<td>39</td>
<td>646</td>
<td>62</td>
<td>12</td>
<td>62</td>
<td>18</td>
<td>2</td>
<td>1298</td>
<td>1252</td>
</tr>
<tr>
<td>5:00-5:15</td>
<td>494</td>
<td>44</td>
<td>699</td>
<td>64</td>
<td>12</td>
<td>57</td>
<td>12</td>
<td>4</td>
<td>1384</td>
<td>1336</td>
</tr>
<tr>
<td>5:15-5:30</td>
<td>563</td>
<td>43</td>
<td>716</td>
<td>58</td>
<td>12</td>
<td>59</td>
<td>14</td>
<td>3</td>
<td>1466</td>
<td>1403</td>
</tr>
<tr>
<td>5:30-5:45</td>
<td>519</td>
<td>42</td>
<td>749</td>
<td>66</td>
<td>6</td>
<td>59</td>
<td>9</td>
<td>4</td>
<td>1452</td>
<td>1388</td>
</tr>
<tr>
<td>5:45-6:00</td>
<td>503</td>
<td>59</td>
<td>772</td>
<td>92</td>
<td>9</td>
<td>54</td>
<td>23</td>
<td>1</td>
<td>1511</td>
<td>1461</td>
</tr>
<tr>
<td>6:00-6:15</td>
<td>573</td>
<td>45</td>
<td>1020</td>
<td>63</td>
<td>13</td>
<td>62</td>
<td>11</td>
<td>4</td>
<td>1788</td>
<td>1661</td>
</tr>
<tr>
<td>6:15-6:30</td>
<td>534</td>
<td>48</td>
<td>941</td>
<td>72</td>
<td>11</td>
<td>44</td>
<td>16</td>
<td>4</td>
<td>1669</td>
<td>1563</td>
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<tr>
<td>6:30-6:45</td>
<td>543</td>
<td>40</td>
<td>953</td>
<td>57</td>
<td>11</td>
<td>45</td>
<td>13</td>
<td>3</td>
<td>1665</td>
<td>1537</td>
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<tr>
<td>6:45-7:00</td>
<td>529</td>
<td>30</td>
<td>886</td>
<td>49</td>
<td>8</td>
<td>44</td>
<td>17</td>
<td>3</td>
<td>1565</td>
<td>1434</td>
</tr>
<tr>
<td>7:00-7:15</td>
<td>480</td>
<td>38</td>
<td>876</td>
<td>71</td>
<td>4</td>
<td>38</td>
<td>14</td>
<td>4</td>
<td>1523</td>
<td>1420</td>
</tr>
<tr>
<td>7:15-7:30</td>
<td>554</td>
<td>40</td>
<td>819</td>
<td>61</td>
<td>5</td>
<td>55</td>
<td>9</td>
<td>3</td>
<td>1543</td>
<td>1448</td>
</tr>
<tr>
<td>7:30-7:45</td>
<td>537</td>
<td>37</td>
<td>784</td>
<td>55</td>
<td>5</td>
<td>49</td>
<td>13</td>
<td>3</td>
<td>1481</td>
<td>1385</td>
</tr>
<tr>
<td>7:45-8:00</td>
<td>486</td>
<td>35</td>
<td>804</td>
<td>51</td>
<td>4</td>
<td>48</td>
<td>9</td>
<td>3</td>
<td>1438</td>
<td>1331</td>
</tr>
<tr>
<td>8:00-8:15</td>
<td>467</td>
<td>32</td>
<td>756</td>
<td>48</td>
<td>3</td>
<td>36</td>
<td>5</td>
<td>3</td>
<td>1347</td>
<td>1243</td>
</tr>
<tr>
<td>8:15-8:30</td>
<td>517</td>
<td>37</td>
<td>894</td>
<td>55</td>
<td>2</td>
<td>42</td>
<td>6</td>
<td>2</td>
<td>1554</td>
<td>1425</td>
</tr>
<tr>
<td>Total</td>
<td>10048</td>
<td>809</td>
<td>15291</td>
<td>1275</td>
<td>169</td>
<td>1039</td>
<td>225</td>
<td>58</td>
<td>2891</td>
<td>27434</td>
</tr>
<tr>
<td>%</td>
<td>35</td>
<td>3</td>
<td>53</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Government bus, † Private and Institutional bus

Figure 3 elucidate vehicle composition and hourly shares of the vehicles, Two wheeler and car proportion in the total volumes are observed as around 53% and 35% respectively whereas buses proportion stand at 4% only. It seems to be an unhealthy proportion with regard to environmental consideration and Level of Service (LOS). The distribution of various vehicles in study corridor is observed that along both directions the flow is almost smooth except during 6:00 p.m to 7:00 p.m.

Table 1 shows the total traffic flow pattern and it is found that peak of peak hours occur from 6:00 p.m to 7:00 p.m with 6686 vehicles per hour. Peak hour factor is 0.93 which indicates the flow variations within the hourly time period is almost uniform. A maximum of 1661 PCUs ply on the stretch in 15 minute period. Vehicle compositions have been calculated based on the collected volume count data. Since India has heterogeneity in its traffic composition, it is vital to collect data on its mode share so as to get a clear picture of proportion of various categories of vehicles in the traffic flow. Figure 3 elucidate vehicle composition and hourly shares of the vehicles, Two wheeler and car proportion in the total volumes are observed as around 53% and 35% respectively whereas buses proportion stand at 4% only. It seems to be an unhealthy proportion with regard to environmental consideration and Level of Service (LOS). The distribution of various vehicles in study corridor is observed that along both directions the flow is almost smooth except during 6:00 p.m to 7:00 p.m.
7.2 Origin – Destination (O-D) Survey

In order to assess the component of traffic along Chennai IT Corridor, Origin - Destination surveys have been carried out for 24 hours on a sample basis of around 20% to 40%. Information regarding origin, destination of the trip, trip frequency, commodity type and purpose of the trip are collected by road side interview method. The O-D survey results provide a clear indication of the zones that contribute to the traffic on the existing roads. Number of trips originating from and destined to any zone represents the influence of that zone on the traffic.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Commercial Vehicles</th>
<th>Passenger Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chennai City</td>
<td>50%</td>
<td>49%</td>
</tr>
<tr>
<td>Rest of CMA</td>
<td>9%</td>
<td>4%</td>
</tr>
<tr>
<td>Pondicherry</td>
<td>38%</td>
<td>44%</td>
</tr>
<tr>
<td>Chengalpattu</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Sripurumbudur</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Tiruvallur</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Tada</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

*Source: L&T Ramboll ORR, 2014*

The above result (Table 2) indicates the influence area of the traffic is within Chennai city and the share of traffic is predominantly from internal to external and vice versa is around 88%. The trip frequency is mostly twice the time of daily for both passenger and commercial vehicles.

7.3 Speed and Delay Study

The detail of delay and travel time of speed-delay survey along the study corridor is conducted on a typical working day during morning hours by using standard vehicle (car). It is observed that, on an average, vehicle can traverse at a speed of 31 kmph towards Kelambakkam direction and 32 kmph towards Madhya Kailash direction. The delay is found to be more due to two major reasons, namely, signalized intersections and U-turn movements. Overall delay is in the order of 10 minutes towards Kelambakkam and 14 minutes towards Madhya Kailash.

7.4 Analysis of Land Area

The optimum utilization of land resource in a well planned manner is very essential. Landuse is a classification by which a piece of land is assigned a particular use and has a planned development. Undeveloped development results in congestion, environmental degradation. Hence it is required to study the landuse changes over a period and offer solutions using spatial techniques like remote sensing and Geographic Information System (GIS) tools and the study area are digitized by using Arc GIS software and thereby the extent of landuse is obtained. Figure 4 shows the land use disposition map of Chennai IT corridor with 1.0 km buffer zone.

8 SYSTEM DYNAMICS SIMULATION MODELING

System dynamics has a long history as a modeling paradigm with its origin in the work (Forrester 1969), who developed the subject to provide in understanding of strategic problems in complex and dynamic systems. System dynamics model, by giving insight feedback processes, provide system uses with a better understanding of the dynamic behaviour of systems. Areas of application of system dynamics have always been very wide, however, with an emphasis on socio-economic applications.

8.1 Land Use Sector Model Building

In this Sector, various landuse disposition of the base year is obtained from the primary analysis of land area along the study corridor with 1 km buffer zone using ArcGIS software. Hence the Land Use sector model is developed in each category of land use with respective with growth rates. The land use model is shown in Figure 5, the model is simulated for various land use disposition of along the study area from base year 2015 to horizon year 2026.

8.2 Transport Sector Model Building

Based on the causal loop diagram, the System Dynamics model for addressing the interaction between land use and transport sector has been developed which is given in figure 6.
Figure 4. Process of Land Use disposition Analysis in GIS

Figure 5. System Dynamics model for Land Use sector

Figure 6. System Dynamics model for Transport sector
9 SCENARIO ANALYSES

9.1 Scenario – I Do Minimum (Allowing existing trend to continue)

In the Scenario I, the existing trend of growth rates of different land uses like Mixed residential, IT Industry / Industry, Commercial, Institutional have been allowed to continue till the year 2026. The system dynamic simulation model is developed for transport sector with different landuse trip rates from that total trips of the different land uses are obtained. These total trips have been converted into total volume with respective occupancy ratio. At last the main result is simulated in terms of volume/capacity (V/C) ratio; this V/C ratio reveals that level of service of the corridor. The result is depicted in the Table 3 and it is observed that the V/C ratio varies from 0.83 in the base year 2015 to 3.13 in the horizon year 2026 which is about 4 times increase when compared with base year data. It is the worst situation obtained if the present trend is allowed to continue till the horizon year. Hence, it should be counter acted with respect to proper planning measures and preventive methodologies to bring down the V/C ratio of the corridor.

Table 3. System Dynamics Results for Scenario I

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>V/C</td>
<td>0.83</td>
<td>0.93</td>
<td>1.04</td>
<td>1.17</td>
<td>1.28</td>
<td>1.45</td>
<td>1.65</td>
<td>1.89</td>
<td>2.16</td>
<td>2.39</td>
<td>2.70</td>
<td>3.13</td>
</tr>
</tbody>
</table>

9.2 Scenario – II Partial Condition (Increasing the capacity of the corridor)

In this scenario, simulation has been carried out such that increasing the capacity of the corridor in terms of providing elevated corridor along the study stretch. Here, the proposed corridor capacity is also considered which would be a four lane divided road with reference to feasibility study report to be operated in the year 2021. The system dynamics model results are shown in Table 4. This increase in capacity results in reduction of V/C ratio from 1.89 to 1.01 in the year 2022 and also 3.13 to 1.52 in the horizon year 2026. Compared to scenario I, the V/C ratio is decreased to 51%. This is only a medium term solution and increasing the capacity alone is not sufficient, as reduction in V/C ratio in 2026 is not to the expected level of less than one. Hence the, scenario III is attempted to achieve better LOS.

Table 4. System Dynamics Results for Scenario II

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
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<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>V/C</td>
<td>0.83</td>
<td>0.91</td>
<td>1.00</td>
<td>1.11</td>
<td>1.19</td>
<td>1.31</td>
<td>1.46</td>
<td>1.01</td>
<td>1.12</td>
<td>1.22</td>
<td>1.35</td>
<td>1.52</td>
</tr>
</tbody>
</table>

9.2 Scenario – III Desirable Condition (Augmentation of public transport and restricting the personalised vehicles)

It is not possible to escalate the transportation infrastructure facilities at all times. Hence, in order to establish a sustainable solution, the present public transport should be augmented from the composition of 4% to 43% and also restricting the composition of personalized vehicles from 88% to 47%. This desirable solution will retain the level of service at the same level till the horizon year 2026 which is shown in Table 5 or even enhanced further from the 2026 level of service.

Table 5. System Dynamics Results for Scenario III

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>V/C</td>
<td>0.83</td>
<td>0.87</td>
<td>0.93</td>
<td>0.98</td>
<td>1.00</td>
<td>1.06</td>
<td>1.13</td>
<td>0.74</td>
<td>0.77</td>
<td>0.80</td>
<td>0.83</td>
<td>0.85</td>
</tr>
</tbody>
</table>

10 RESULTS

Table 6 shows the results obtained from the system dynamics simulation model towards sustainable solution of the corridor. This study could be used to help in evaluating whether the development is appropriate for a site and what type of transportation improvements may be necessary in order to maintain a satisfactory level of service (LOS).

Table 6. System Dynamics Results of the Traffic Impact Analysis of the Corridor

<table>
<thead>
<tr>
<th>Scenario</th>
<th>V/C Ratio</th>
<th>Inference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do Minimum</td>
<td>0.83</td>
<td>3.13</td>
</tr>
<tr>
<td></td>
<td>2015</td>
<td>Compared with 2015, more than 3 folds increase.</td>
</tr>
<tr>
<td>Partial Condition</td>
<td>0.83</td>
<td>1.52</td>
</tr>
<tr>
<td></td>
<td>2026</td>
<td>Compared with Do min, reduced more than 50%.</td>
</tr>
<tr>
<td>Desirable Condition</td>
<td>0.83</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>2015</td>
<td>Compared with partial, reduced more than 40%.</td>
</tr>
</tbody>
</table>
RECOMMENDATIONS

- To achieve the desirable V/C ratio of 0.85 in the horizon year 2026, an augmentation of public transport should be increased to 43% and simultaneously the personalized vehicles should be restricted to 47%.
- At present, maximum allowable Floor Space Index (FSI) in Chennai IT corridor is 3.75 for IT/ITES land uses and 2.5 for other than IT/ITES. Hence, it is recommended to increase the mixed residential FSI from 2.5 to 3.5 because of the growth potential along study corridor. According to the model results, there is a greater need for mixed residential land use.
- The government could implement soon, the proposed elevated expressway and BRTS to public in year 2019 instead of 2021. This reduces the V/C ratio and increase the LOS to a greater extent.
- Since the results of partial scenario prove to be much better than minimum condition, it is recommended that even if the desired condition cannot be achieved at least the government should strive towards achieving partial results.
- TIA is one of the environmental impact assessments (EIA) and must be addressed in an environmental impact report (EIR), which must be certified by concern authority before any developments permit could be issued.
- TIA study is not only suggesting short term management measures but also it is capable of addressing the problem in a holistic way through system dynamics simulation modeling effort to ensure sustainable solutions.
- Normally, TIA study is assessing the total trips generating by any proposed (individual) development and what is the impact on the intersections nearby. In this TIA study deals with, total trips generating by all kind of developments along the corridor and predict the existing or future transportation infrastructure can accommodate the same.

REFERENCES


Mathew Martimo, “ITE trip rates, 9th Edition” mail received mail (mmartimo@citilabs.com) on 30.03.2015, CITILABS, FL 32304 USA.


ABSTRACT:

Turkey’s Motorway Network maintenance and repair is too high to reach for the requirements of the budget because of limited resources available in our country of resources in a more efficient use, to the motorway network, roads, Pavement Management System implementation has become mandatory to have. Pavement Management System (PMS), limited to an existing budget, to provide the highest gain optimum maintenance / improvement programs to create a priority objective and systematic approach to move.

In this study, two performance prediction new methods have been developed by using fuzzy logic and regression analysis methods to predict, depending on deformation and performance parameters, when the deformations in the pavement of motorways will happen. Flow diagram of Pavement Management System has been developed to plan rehabilitation facilities at the network level according to performance prediction values.

In this study, IRI, roughness index values that are measured on the 886,4 km long motorways with 2x3 lanes have been predicted by using regression analysis and fuzzy logic methods. While conducting this analysis we used 11 different climatic parameters that affect pavement’s life-span, and pavement temperature data that are calculated according to changes in temperature and traffic load values. The values that are predicted from the model results are compared with the real values that are measured in the field. Accuracy of the new models have been comparatively evaluated.
A Modeling Of The Motorway Network Performance Prediction With Fuzzy Logic And Statistical Analysis Methods

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1 INTRODUCTION

Evaluation of an existing motorway network and determination of the necessary maintenance strategies are made through pavement maintenance-repair systems. Pavement Management System, ÜYS, requires an objective and systematic approach that will help to create maintenance-rehabilitation programs, which will provide maximum amount of gain with a limited budget (Holt and Gramling 1992).

Pavement management is the totality of the facilities that include all the activities such as the creation of optimal strategies at various management levels, implementation of these strategies, data collection, evaluation, renovation, care and repairation. It is also responsible to periodically control the service level of the Pavement (Tmh 9 1992). The function of the Pavement management system is make decisions via coordinating between the units related to the management, interpreting the results of these decisions, and to provide the consistency of the decisions that are made at different management levels within the same organization (Amsc 2008).

The research in the AASHO motorway experiment has shown that pavement service ability can be determined from surface profile and geometric roughness with 95 % reliability (Carey and Iric 1960). IRI, roughness index that shows the driving comfort is calculated with the vertical profile of the pavement, which is obtained from the profile-meter measurements. International Roughness Index (IRI), while it is an index showing the state of the pavement, also explains values of driving quality, traffic security and vehicle care costs (Sayers, Gillespie and Queiroz 1986).

ASTM E1889-97 standard guide is published for PMS to be usable. This guide sets the effective rules that will help system engineers to control the process and paths in the management and implementation of PMS, and intervene when necessary (Astm E1889-97 2002).

In this study, Motorway performance evaluation has been carried out by considering the roughness measurement results, deformation assessments throughout the motorway occasional rehabilitations and Pavement projections (Sauti 1971). In the motorway sections under investigation, all variants such as the traffic data, which is the equivalent standard axle load that causes deformations in the pavement, climate data, pavement thickness and the state of the surface are taken into consideration. Model output, however, is the IRI, roughness index values. Among the models that are developed for the classifications of the deformation relations that took place in time, Figure 1. shows the regression model; Figure 2. shows fuzzy logic model with their most common structure. (Hergün 2009) In the modeling, Sugeno type fuzzy inference system was used, and a fuzzy modeling has been created based on group prediction (Chu 1994). Training of the system has been done with the use of an algorithm, which makes rule appointment by grouping the input data. In this algorithm, group centers are determined by classifying data conglomerates; rule appointments are done to these centers (Şen 2004, Baykal and Beyan 2004).
2. Material and Methodology

In order to create a deformation model that will predict IRI values equivalent of the irregularity values, we will do a performance prediction modeling by using, first, a multi-layered regression analysis, then fuzzy logic modeling. The results of both models are compared with the real values. (Transportation Master Plan 2010)
2.1. Multi-layered regression and variance analysis for IRI

The input data that were taken into consideration in the models is one of the most important security parameters that determine the service duration of the Pavement, and very influential on its performance. (Alpar 2003) First of all, the Annual Average Daily Traffic (AADT) change values from the year, in which the motorway sections under investigation were opened to traffic for light and heavy vehicles, to the years, in which the roughness measurements were taken, were assessed. Using this data the Total Standard Axle Load Repeat Number $T_{82}$ has been found for every year under the rules stipulated in the Flexible Pavement Design Manual of the Directorate (General Directorate Of Highway 2006).

If the year of maintenance of the motorway section is stated, these values have been brought to the year, in which the roughness measurements were done, from that year onwards. If it is not stated, then the year of the opening to traffic was used (General Directorate Of Highway 2006-1).

As in traffic parameters, climate parameters are used by being brought agglomeratively from the year of maintenance for each section of the motorway to the time when the roughness measurements were taken, if that information is known (General Directorate of Highway 2003-2006). If not, the year of opening to traffic was used (İyinam 1997), (General Directorate of Highway 2006-2). The main parameters of the deformation model that will be created with the aid of regression analysis to predict the Pavement performance are the IRI measurements, agglomerated $T_{82}$ values that correspond to the year when the measurements were done, climate data and the thickness of the Pavement. At the beginning, precipitation (snow and rain), humidity, temperature, pavement temperatures, and frost index values were used as climate data (Ministry of Environment Forests 2006). The high pavement temperature 20mm below the pavement surface and the low pavement temperature assessed at the surface were used as pavement temperatures. Maximum and minimum weather temperature values were converted into pavement temperature values on monthly periods by using the relation stated in the Superpave method (Asphalt Institute 1996). (Eq. A.1 and Eq.A.2)

\[
T_{20} = 0.9545\left(T_{\text{weather max}} - 0.00618E_n^2 + 0.2289E_n + 42.2\right) + 17.78 \quad (1)
\]

\[
T_{\text{surface}} = 0.859T_{\text{weather min}} + 1.7 \quad (2)
\]

$T_{20}$ : High pavement temperature 20mm below the surface
$T_{\text{weather max}}$ : Monthly maximum weather temperature value
$T_{\text{weather min}}$ : Monthly minimum weather temperature value
$E_n$ : Geographic latitude of the motorway section

Therefore, “Standard Axle Load Repeat Number values”, “Annual High Pavement Temperature Total Repeat Number” (AHPT TRN) and 1/Annual Low Pavement Surface Temperature Total Repeat Number (1/ALPST TRN) are independent variables in the study and used as model parameters.

It has been observed that pavement thicknesses did not have any effect in the model due to the fact that the thickness data taken from the motorway sections and used in the model were in the same. Model summary is in Table 1, and Linear dependence is in Table 2.

<table>
<thead>
<tr>
<th>Model</th>
<th>$R^2$</th>
<th>$R^2$</th>
<th>Corrected $R^2$</th>
<th>Std. Error of Prediction</th>
<th>$R^2$</th>
<th>$F$</th>
<th>df1</th>
<th>df2</th>
<th>Meaningfulness of the $F$ Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.937a</td>
<td>.879</td>
<td>.866</td>
<td>.14362</td>
<td>.879</td>
<td>70,114</td>
<td>3</td>
<td>29</td>
<td>.000</td>
</tr>
</tbody>
</table>
Table 2. Model coefficient and linear dependency situation

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized coefficients</th>
<th>Std. Coef</th>
<th>t</th>
<th>Meaningfulness</th>
<th>%95 Confidence Interval (for B)</th>
<th>Natural Dependency Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>.906</td>
<td>.098</td>
<td>9.226</td>
<td>.000</td>
<td>.705 - 1.106</td>
<td></td>
</tr>
<tr>
<td>T82</td>
<td>1.15E-8</td>
<td>.000</td>
<td>.801</td>
<td>.000</td>
<td>.000 - .000</td>
<td>.567 - 1.763</td>
</tr>
<tr>
<td>AHPT TRN</td>
<td>3.07E-6</td>
<td>.000</td>
<td>.305</td>
<td>.023</td>
<td>.000 - .000</td>
<td>.259 - 3.856</td>
</tr>
<tr>
<td>1/ALPST TRN</td>
<td>-125.72</td>
<td>59.95</td>
<td>-.222</td>
<td>.045</td>
<td>-248.34 - -3.11</td>
<td>.371 - 2.693</td>
</tr>
</tbody>
</table>

The model that is created with the coefficients in Table 2;

\[
IRI = 0.906 + 1.154 \times 10^{-8} \times T_{82} + 3.068 \times 10^{-6} \times \text{AHPT TRN} - 125.728 \times (1 / \text{ALPST TRN})
\]  

(3)

The graphics, which show the IRI values predicted with the real field IRI values and by the regression model, are given in Figure 3.
The change of the IRI value that belong to each motorway section under consideration from its construction over a 20 year long period is given in Figure 4.

2.2. The fuzzy logic method for the prediction of the IRI values

There are 1 output variable for 3 inputs in the fuzzy model structure formed in this study. The input variables are the traffic parameter, T8.2 Equivalent Standard Axle Load value, as related to the climate parameters, Annual High Pavement Temperature Total Repeat Number (AHPT TRN) and 1/Annual Low Pavement Surface Temperature Total Repeat Number (1 / ADPST TRN). The output variable is the IRI roughness value. In the modeling, Sugeno type fuzzy inference system was used, and a fuzzy modeling has been created based on group prediction (Chiu 1994).

Training of the system has been done with the use of an algorithm, which makes rule appointment by grouping the input data. In this algorithm, group centers are determined by classifying data conglomerates; rule appointments are done to these centers (Şen 2004), (Baykal and Beyan 2004).
For performance modeling, 26 from 42 data groups are selected for training; 4 for control; and 12 for testing. Gaussian membership function was used in the input variables of the fuzzy model. At the end, the data group has been defined in 6 fuzzy rules in most suitable way by the help of rule appointments. See Figure 8.

Figure 8. Fuzzy inference model (System; 3 inputs, 1 output, 6 rules)

Membership functions of $T_{8.2}$ Equivalent Standard Axle Load value can be seen in Figure 9. Along with the membership functions of Annual High Pavement Temperature Total Repeat Number and Annual Low Pavement Surface Temperature Total Repeat Number. The results of the fuzzy model are given in Figure 10. The graphics shown in this visual are created by the program module, which is written with Matlap program.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure8}
\caption{Fuzzy inference model (System; 3 inputs, 1 output, 6 rules)}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure9}
\caption{Membership functions of equivalent standard axle load value (ESALV)}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure10}
\caption{Membership functions of annual high pavement temperature total repeat number (AHPTTRN)}
\end{figure}
c. The Membership functions of annual low pavement surface temperature total repeat number (ALPST - TRN)

Figure 9. Membership functions

a. Comparison of the real IRI values with the IRI values calculated with the model.

b. Model parameter relation graphic

Figure 10. Graphics showing the results of the fuzzy model
2.3. Comparison of the results of regression and fuzzy logic models.

The data that are used to test in the fuzzy logic modeling is also used in the comparison of the results of the regression and fuzzy logic models discussed above. Based on these data, the IRI measurements that were taken in the field are compared with the IRI values calculated with the models (Table 3).

Table 3. Comparison of the IRI measurement results and the model results.

<table>
<thead>
<tr>
<th>IRI TEST DATA</th>
<th>IRI MEASURED IN THE FIELD</th>
<th>IRI ACCEPTANCE INTERVAL (IRI m/km)</th>
<th>MODEL RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARAMETERS</td>
<td></td>
<td></td>
<td>FUZZY LOGIC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IRI</td>
</tr>
<tr>
<td>T8.2</td>
<td>109991</td>
<td>0.77</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>10946094</td>
<td>1.23</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td>16059765</td>
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<td>1.58</td>
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<td></td>
<td>25553241</td>
<td>1.32</td>
<td>1.40</td>
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<td></td>
<td>37127846</td>
<td>1.54</td>
<td>1.35</td>
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<td></td>
<td>44510851</td>
<td>1.63</td>
<td>1.23</td>
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<td></td>
<td>52798589</td>
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<td>1.63</td>
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<td>1.70</td>
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<td></td>
<td>17825137</td>
<td>1.34</td>
<td>1.41</td>
</tr>
<tr>
<td></td>
<td>46629520</td>
<td>1.66</td>
<td>1.65</td>
</tr>
<tr>
<td>CORRELATION</td>
<td>0.968839</td>
<td>0.950679</td>
<td>0.0725</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.0725</td>
<td>0.1201</td>
<td>0.012</td>
</tr>
<tr>
<td>ME</td>
<td>0.012</td>
<td>0.080</td>
<td></td>
</tr>
</tbody>
</table>

3. CONCLUSIONS

1. A multi-layered regression analysis and a new performance model with the use of fuzzy logic method have been developed in order to evaluate the condition of motorway network’s pavement and to predict its future performance, in addition to developing a pavement management system, the aim of which is to cultivate a conceptual design and establish a plan that is applicable to the entire country. The predictions that are to be made are dependent on,
   - IRI values, which denote roughness value,
   - Traffic load, which is denoted by T8.2 Equivalent Standard Axle Load,
   - And pavement temperatures calculated according to climate data.

2. In this study the international standard measurement IRI roughness index values, 11 different climate parameters, which affect pavement’s service duration, and pavement temperature data that are assessed out of those parameters are uniquely used for the first time in a performance prediction model developed for the motorway network.

3. Therefore, “Standard Axle Load Repeat Number values”, “Annual High Pavement Temperature Total Repeat Number” (AHPT TRN) and 1/Annual Low Pavement Surface Temperature Total Repeat Number (1/ALPST TRN) are independent variables in the study and used as model parameters.

4. A regression model and a fuzzy modeling based on group prediction are created and compared in this performance prediction model that is developed to found a Pavement Management System for the motorway network.

5. In the motorway sections where cement connecting and granular foundation layer is used in the pavement, and where the temperature change differences between the day and night is maximum, the most influential parameter that causes deformations is not T8.2 Equivalent Standard Axle Load values, but pavement temperature values. In other words, in the motorway sections where the difference between the highest and the lowest weather temperature values equals or greater than 15°C, change in pavement temperatures are the most important parameter that cause deformations.
6. It has been found that the pavement performances in the motorway sections under investigation; decreased directly proportional to the High Pavement Temperatures change at the asphalt layer, which is calculated according to the highest weather temperature, decreased indirectly proportional to the Low Pavement Surface Temperature change values at the asphalt surface, which is calculated depending on the lowest weather temperature.

7. It has been observed that pavement thicknesses did not have any effect in the model due to the fact that the thickness data taken from the motorway sections and used in the model were in the same.

8. When we compare the models with each other, we see that the correlation coefficient between the roughness index values calculated with the fuzzy logic model and the real roughness index values is higher than the correlation coefficient between the regression model and the real roughness index values. Additionally RMSE and ME values are smaller than the regression model results. These findings prove that fuzzy logic models have higher prediction powers compared to regression models.

9. This study has set it clear that, with the IRI values that are predicted for the future performance of a motorway network, it is possible to foresee which part of the motorway will require intervention when (which year), and what the best method of maintenance will be.

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ALPAR, R., (2003). Application Multiple Linear Statistical Methods Input 1 Nobel Publisher, Ankara, TURKEY.
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ABSTRACT: Outsourcing, privatization, and borrowing management practices from the private sector such as strategic and performance planning, performance management, have been a backbone of the new public management paradigm of the last three decades. As a new public management practice, the performance based contracting applications have been highly acknowledged by the public agencies in order to link effectively their strategy and performance management with each other. Additionally, it has been seen that the performance based contracting serves the new public procurement reforms that are claimed or assumed as a response to existing deficiencies stemming from traditional one.

The main interest to the innovative contracting methods is seeking remedies for minimizing construction time and cost, improving quality by either providing specifications for quality control and inspection or warranties, and most importantly, transferring some risk from the public agency to the contractor. Because its specifications are strictly focused on materials and method, the traditional approach in contracting (design-bid-build) for public sector projects, in which design is carried out independently of the construction process, is inadequate to meet modern expectations in terms of quality, timeliness and customer’s expectation for the agencies. Therefore, the public agencies (contracting authorities) must clearly move away from their traditional methods to performance based long term contracting approaches. Performance based maintenance contracting that is appreciated as a key step for the innovative contracting methods in highway maintenance has been analyzed in this study.

Firstly, the results based management and its principles, such as performance indicators on the road sector have been introduced. Secondly, innovative contracting methods and its different aspects have been analyzed by using broadly international perspectives and applications. Thirdly, Turkish experiences have been analyzed in the perspective of a survey study carried out as a part of the study. Consequently, If the authority must take necessary steps listed on the results section for effective use of performance based contracting, it has shown that it might be very promising and beneficial tool for the public procurement system in Turkey.
1. Introduction

After 2001 the financial and economic instability, Turkish electorates penalized the former coalition parties and paved the way for single party government in 2002. The newly founded government showed strong commitment to EU membership goal, carried out liberal economic reforms, and provided political stability. (Öniş, 2012) As a result of these structural changes allowed public and private capital investments to flourish. “Construction of 15,000 km dual highway”, which was one the of the public policy measures of the urgent action plan announced by the ruling party in 2002 after formed the government, has long been controversial issue among transport specialists. Nevertheless, General Directorate of Highways (KGM) has managed to build 17,110 km divided highways during the last decade so 4,387 km divided highway road network in 2002 has reached to 21,497 km by 2015 in 63,143 km state and provincial road network in charge of KGM.

Increasing capital investment via constructing dual highways in road network has come in for a couple of remarkable critics. First, increasing capacity of road network would be reversal of the balanced transportation policy set in the strategic documents and policy papers in which modal shift was defined as a government priority. Therefore, it was argued that the government should give policy preference to railways and port investments rather than dual highway construction projects. As a matter of fact, the multimodal investment policy approach, the share of other transport modes in total spending hasn’t been increased with respect to road for the last decade.

![Figure 1. Road Maintenance as a share of GDP with respect to Japan](source)

Second, it has been argued that the great majority of road capacity investments (dual highways) has been realized in the least mobile region of Turkey where the AADT (Average Annual Daily Traffic) is below the feasible level for capacity improvement investments. Since Turkey has weak interurban transport demand but
severe congestion problem in its megacities like Istanbul, overcapacity design in interurban road network had caused to higher opportunity cost of capital while municipality infrastructure needs capital investments.

Finally, it has been claimed that dual highway investments crowded out the road maintenance expenses and Turkey’s maintenance expenditures are still far below the expected level (Figure 1). According to Worldbank (2012), highway maintenance expense during 2005-2010 was only realized 45 percent of the required level. Maintenance and capital investments were competing each other for bigger share of funds. Because new capital investment projects such as dual highway construction were politically more attractive than maintenance expenditure, the road authority has chosen to postpone road maintenance. Even if postponing maintenance would be eventual loss of development in national economies, policymakers and bureaucrats tend to allocate more resources to Greenfield projects. Because these economies have not sound asset management systems and tangible indicators to measure their success in infrastructure management, greenfield projects benefit from having relatively measurable output indicators.

However, road authorities have been highly oriented to adopt private sector practices and tools such as strategic planning, and asset management for the last decades compared to other public agencies. Because they have an advantage to work with tangible indicators to measure their output, they inspire advisers with hope to increase management efficiencies in maintaining road network. In this respect, KGM was one of the eight pilot public organizations that were selected to launch strategic planning process in 2003 and subsequently strategic planning has been adopted the other Turkish public agencies based on the experiences of the pilots. Although KGM has adopted by strategic planning approach relatively early, KGM’s strategic planning experience is still far from bringing satisfactory results to transform road management into more efficient and effective system.

Although KGM could not be evaluated as successful adopter of strategic planning paradigm, some obstacles could be inferred for effective implementation of strategic planning; KGM’s strategic plans lack focus on outcomes rather than input and outputs. Additionally, the link between budget and performance measures have yet to be successfully and effectively established. More importantly, performance based approach has not been internalized by public employees yet and the whole process points out that the transformation process needs to be done gradually.

To overcome these problems, new innovative contracting methods such as performance based contracting could be helpful have recently been acknowledged by the public agencies in order to link effectively their strategy and performance management with each other and provide gradual transformation to have performance oriented organizations. Besides, it is seen that performance based contracting serves new public procurement reforms that are claimed or assumed to be a response to existing deficiencies stemming from traditional ones.

KGM took the first step toward performance based contracting by publishing the decree titled “Pavement Performance Criteria and Payment Conditions” in which specific values of the performance indicators (Skid Number (SN) and International Roughness Index (IRI)) were used as disincentive benchmark for the contractors in 2008. The terms of the decree are required to be used only on Bituminous Hot Mixture (BHM) Replacement Works and it makes the contractors follow the technical specifications attached to the contracts. It determines the amount of payments to be made to the contractor based on its ability to meet performance targets. If the contractor meets the performance target, the contractor deserves to have full payment; otherwise, 5%, 10% discount on the payment or reconstruction punishments under the certain thresholds are enforced. Because the contract defines technical specification which describes what methods and materials the contractor have to use/obey in detail, it couldn’t be classified as performance based contract technically even if it has performance measures. Thanks to the new contracting on 1,478 km highway, only 61.3% of the contractors deserved to full payment, whereas 22.8% had 5% discount, and 5.3% was sentenced to reconstruction penalty at the first year of the decree’s application in 2009-2010. As a result, the performance of the contractors dramatically improved and full compliance to the performance rate soared to 70.9% level in 2011.

However, it is hard to say that the successful results acquired in BHM constructions are fully internalized in other construction works, specifically in maintenance works. Although the fundamental policy documents stressed to ensure delivery of maintenance and repair services mostly by private sector, it is highly debatable whether it can be implemented successfully since KGM and the contractors lack experience in maintenance outsourcing. This study, using web-based survey data from the professionals contribute to the debate by providing evidence how KGM employees perceive the performance based contracting and outsourcing maintenance activities which have been traditionally perceived as in-house activities. The following section summarizes the methodology applied and the next sections outline and discuss the results of the survey. The last section includes conclusions and policy implications.
2. Methodology

The Survey aims at understanding:

- How the staff of KGM evaluates their own performance in infrastructure development;
- Which institutional strengths and weaknesses of KGM come into prominence;
- Whether contractual arrangements or procurement strategy such as PBC may help to solve institutional problems;
- What institutional aspects should be taken into account to adopt performance based contracting methods, primarily on road maintenance, in the light of knowledge and experiences coming from daily routines;
- What KGM officials thought about possible PBC options;

The web-based questionnaire was designed to gather data from the key officials in KGM. The e-mail accounts of 5,500 employees recorded in the Department of Information were obtained and the questionnaire was sent to these accounts in July 2012. The account holders were selected as target officials as they were mostly involved in daily routines, decision making and/or executive process.

Table 1 provides the details of the contacted participants and response rates. While participation rate was about 11% (626 participants), male participation rate (79.9%) was higher than female (20.1%) participation. This higher gender difference detected in the survey shows male dominated sector as expected. Figure 2 presents the participants’ education profile and Figure 3 presents distribution of their duties.

Table 1. Participants Gender Profile

<table>
<thead>
<tr>
<th>Gender</th>
<th>Response Percent</th>
<th>Response Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>79.9%</td>
<td>498</td>
</tr>
<tr>
<td>Female</td>
<td>20.1%</td>
<td>125</td>
</tr>
<tr>
<td>answered question</td>
<td></td>
<td>623</td>
</tr>
<tr>
<td>skipped question</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 2. Educational Profile

The questionnaire most widely attracted the engineers’ attention (27.6%) in an occupational classification. The limited number of high-level officials participated to the survey in a classification of assigned positions in KGM. Nonetheless, keeping in mind that limited number of high-level positions available (10 Department and 19 Regional Directorates), the participation of 2 Head of Regional Directorate
and 7 Deputy Head of Regional Directorate and 3 Head of Department is highly remarkable figure showing recognition of the questionnaire by the officials.

Experience profile also shows that the participants who were working 15 years or longer had the biggest share (43.7%) while the less experienced group who were working 5 years or less was the second one (27.8%) implying that the survey largely attracted master and apprentice level officials’ attention (Table 2). Additionally, the question whether they have any idea or experiences about performance based contracting had been asked and 22.5% of respondents answered yes while 77.5% of whom said no. This result was reasonable and expected because performance based contracting had not been applicable method in Turkey.

Table 2. Tenure of Services

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Response Percent</th>
<th>Response Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between 0-5 year</td>
<td>27.8%</td>
<td>173</td>
</tr>
<tr>
<td>Between 5-10 years</td>
<td>15.9%</td>
<td>99</td>
</tr>
<tr>
<td>Between 10-15 years</td>
<td>12.7%</td>
<td>79</td>
</tr>
<tr>
<td>More than 15 years</td>
<td>43.7%</td>
<td>272</td>
</tr>
<tr>
<td>answered question</td>
<td></td>
<td>623</td>
</tr>
<tr>
<td>skipped question</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

3. Results

Assessment of Service Quality

The first part of the questionnaire aimed at assessing the current performance of the services provided by KGM. The respondents who were also KGM employees first asked to assess the services provided by their institution, using a scale from 1 to 5 (from very good to very bad). It is naturally expected that the results may be biased because employees’ loyalty and/or other commitments to their own workplace may lead them to subjectivity. However, KGM employees are both servants and users of highway system so it is also reasonable to assume that they weren’t isolated from the problems and challenges faced by other road users.

Table 3 shows the distribution of responses, which implied that the respondents tended to assign good rating the services which were listed as road construction and its integral parts: geometric standards,
horizontal and vertical markings. Almost 60% of respondents valued that these services were satisfactory. Remarkably, winter maintenance had highest score (80%) but it could be misleading because the winter conditions (mild in 2011) during the year of the survey may result in overrating. On the other hand, respondents reported that KGM was relatively unsuccessful in answering environmental concerns, and providing rehabilitation services which is essential for diminishing life-cycle cost of the assets.

Table 3. Assessment of Services Quality

<table>
<thead>
<tr>
<th>What is your opinion about the qualities of the services given by Directorate General of Highways? (If you don't have any idea on one issue, you can skip the next one)</th>
<th>Very Good</th>
<th>Good</th>
<th>Fair</th>
<th>Bad</th>
<th>Very Bad</th>
<th>Response Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Construction</td>
<td>72</td>
<td>288</td>
<td>118</td>
<td>23</td>
<td>3</td>
<td>504</td>
</tr>
<tr>
<td>Road Pavement Condition</td>
<td>31</td>
<td>226</td>
<td>185</td>
<td>41</td>
<td>6</td>
<td>489</td>
</tr>
<tr>
<td>Vertical and Horizontal Road Markings</td>
<td>65</td>
<td>292</td>
<td>108</td>
<td>13</td>
<td>6</td>
<td>484</td>
</tr>
<tr>
<td>Geometric Standards of Highways</td>
<td>33</td>
<td>236</td>
<td>149</td>
<td>20</td>
<td>4</td>
<td>442</td>
</tr>
<tr>
<td>Traffic Signs</td>
<td>55</td>
<td>234</td>
<td>159</td>
<td>24</td>
<td>7</td>
<td>479</td>
</tr>
<tr>
<td>Landscaping, noise curtains</td>
<td>28</td>
<td>126</td>
<td>219</td>
<td>92</td>
<td>17</td>
<td>482</td>
</tr>
<tr>
<td>Winter Maintenance</td>
<td>117</td>
<td>278</td>
<td>78</td>
<td>17</td>
<td>3</td>
<td>493</td>
</tr>
<tr>
<td>Routine Maintenance Works</td>
<td>36</td>
<td>232</td>
<td>173</td>
<td>37</td>
<td>6</td>
<td>484</td>
</tr>
<tr>
<td>Rehabilitation Works</td>
<td>18</td>
<td>135</td>
<td>174</td>
<td>66</td>
<td>7</td>
<td>400</td>
</tr>
<tr>
<td>Traffic Safety Measures</td>
<td>42</td>
<td>215</td>
<td>178</td>
<td>34</td>
<td>8</td>
<td>477</td>
</tr>
<tr>
<td>Illumination</td>
<td>41</td>
<td>195</td>
<td>192</td>
<td>49</td>
<td>10</td>
<td>487</td>
</tr>
<tr>
<td>Road Information Services</td>
<td>78</td>
<td>214</td>
<td>119</td>
<td>44</td>
<td>10</td>
<td>465</td>
</tr>
<tr>
<td>Environmental Awareness</td>
<td>38</td>
<td>154</td>
<td>190</td>
<td>71</td>
<td>24</td>
<td>477</td>
</tr>
<tr>
<td>Intelligent Transportation Systems</td>
<td>25</td>
<td>139</td>
<td>173</td>
<td>77</td>
<td>17</td>
<td>431</td>
</tr>
</tbody>
</table>

The second question of the first part of the questionnaire was intended for assessing the current procurement law. Some benefits which are expected to be acquired by outsourcing services were listed and the respondents were asked to how these benefits were affected by the current procurement practices. The respondents tended to evaluate the current procurement and contracting law and their application positively in terms of construction cost and competitiveness perspectives. However, the responses suggest that the quality and occupational health and safety during or after the construction phase were negatively affected by the current practices. Hence the result supports that lower quality and safety are the side effects of devastative competition based on bidding on construction cost (Table 4).

Assessment of Outsourcing Maintenance Works

The second goal of the survey was to determine how KGM officials evaluated the idea of outsourcing maintenance works by using long-term contracts. Three questions were asked for the evaluations: First one, some benefits which are generally expected to be acquired by outsourcing services were listed and the respondents were asked how far they agree that these benefits could be achievable by outsourcing maintenance works. The results showed that the respondents who supported that the benefits of outsourcing could be achievable were taking majority in the survey. Over the 70% of the respondents argued that outsourcing would result in savings from personnel expenses, material and equipment cost. Additionally, the claims which were the outsourcing may decrease the cost of maintenance, increase know-how transfer between public and private partners, and lead to innovation were also supported by the respondents. On the other hand, the survey didn’t suggest any results on the effects of quality, safety and user satisfaction on outsourcing maintenance activities (Table 5).
Table 4. Assessment of Current Contracting Methods

<table>
<thead>
<tr>
<th>How are these issues affected by the application of the current contracting methods and technical specification? (If you don't have any idea on one issue, you can skip the next one)</th>
<th>Very Positively Affected</th>
<th>Positively Affected</th>
<th>Not Affected</th>
<th>Negatively Affected</th>
<th>Very Negatively Affected</th>
<th>Response Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Cost</td>
<td>10,58%</td>
<td>41,99%</td>
<td>10,90%</td>
<td>32,05%</td>
<td>4,49%</td>
<td>312</td>
</tr>
<tr>
<td>Procurement Competition</td>
<td>11,56%</td>
<td>48,75%</td>
<td>11,88%</td>
<td>24,38%</td>
<td>3,44%</td>
<td>320</td>
</tr>
<tr>
<td>Construction Time (without delay)</td>
<td>9,55%</td>
<td>36,94%</td>
<td>19,43%</td>
<td>28,66%</td>
<td>5,41%</td>
<td>314</td>
</tr>
<tr>
<td>Construction Quality</td>
<td>8,66%</td>
<td>28,66%</td>
<td>17,61%</td>
<td>36,12%</td>
<td>8,96%</td>
<td>335</td>
</tr>
<tr>
<td>Occupational Health and Safety</td>
<td>9,49%</td>
<td>26,58%</td>
<td>27,22%</td>
<td>31,33%</td>
<td>5,38%</td>
<td>316</td>
</tr>
<tr>
<td>Traffic Safety</td>
<td>8,10%</td>
<td>32,69%</td>
<td>28,53%</td>
<td>28,53%</td>
<td>4,81%</td>
<td>321</td>
</tr>
<tr>
<td>Life-Cycle Cost (lower cost in operation and maintenance phases)</td>
<td>12,08%</td>
<td>30,20%</td>
<td>17,79%</td>
<td>32,21%</td>
<td>7,72%</td>
<td>298</td>
</tr>
<tr>
<td>User Satisfaction</td>
<td>9,79%</td>
<td>36,39%</td>
<td>21,71%</td>
<td>26,61%</td>
<td>5,50%</td>
<td>327</td>
</tr>
<tr>
<td>Innovative methods and material choices</td>
<td>10,36%</td>
<td>36,57%</td>
<td>23,95%</td>
<td>23,95%</td>
<td>5,18%</td>
<td>309</td>
</tr>
</tbody>
</table>

**answered question** 363
**skipped question** 263

Table 5. Assessment of Outsourcing Maintenance

<table>
<thead>
<tr>
<th>How outsourcing of maintenance works by long-term contracts contributes to current situation (instead of traditional in-house maintenance practices)? (If you don't have any idea on one issue, you can skip the next one)</th>
<th>I strongly Agree (5)</th>
<th>(4)</th>
<th>(3)</th>
<th>(2)</th>
<th>I strongly disagree (1)</th>
<th>Response Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>To increase the quality (Driving Comfort etc.)</td>
<td>92</td>
<td>77</td>
<td>77</td>
<td>38</td>
<td>86</td>
<td>370</td>
</tr>
<tr>
<td>To decrease the cost of maintenance</td>
<td>110</td>
<td>104</td>
<td>49</td>
<td>42</td>
<td>76</td>
<td>381</td>
</tr>
<tr>
<td>To help to use innovative construction methods</td>
<td>102</td>
<td>89</td>
<td>63</td>
<td>50</td>
<td>65</td>
<td>369</td>
</tr>
<tr>
<td>To lead to use more innovative materials (material technology)</td>
<td>99</td>
<td>89</td>
<td>61</td>
<td>55</td>
<td>62</td>
<td>366</td>
</tr>
<tr>
<td>To reduce the need for hiring new public employee</td>
<td>156</td>
<td>117</td>
<td>45</td>
<td>18</td>
<td>43</td>
<td>379</td>
</tr>
<tr>
<td>To increase road safety</td>
<td>72</td>
<td>71</td>
<td>86</td>
<td>61</td>
<td>77</td>
<td>367</td>
</tr>
<tr>
<td>To increase user satisfaction</td>
<td>72</td>
<td>80</td>
<td>85</td>
<td>62</td>
<td>68</td>
<td>367</td>
</tr>
<tr>
<td>To decrease the cost of machinery and equipment needs of the public authority</td>
<td>172</td>
<td>114</td>
<td>36</td>
<td>26</td>
<td>33</td>
<td>381</td>
</tr>
<tr>
<td>To increase accountability</td>
<td>114</td>
<td>82</td>
<td>50</td>
<td>35</td>
<td>81</td>
<td>362</td>
</tr>
<tr>
<td>To increase know-how transfer between public and private partners</td>
<td>111</td>
<td>100</td>
<td>66</td>
<td>30</td>
<td>69</td>
<td>376</td>
</tr>
</tbody>
</table>

**answered question** 402
**skipped question** 224
Assessment of Performance Based Contracts

To assess how KGM officials evaluate performance based contracts, the questionnaire firstly defined what the performance based contract is and made it clear before answering the following questions based on the definition. Given that, “Performance Based Contracts is a kind of contracting method in which contracting payment made to specific performance measures (roughness, skid resistance etc.) and measurable levels of operational performance defined by the public authority and agreed on by contracting parties, and where the public authority leaves the contractor free to choose and apply the construction materials, equipment, employees, and methods he wishes to carry out”, the respondents were asked to rate how far they agree that performance based contracting contribute current practices in the defined manner.

Table 6. Assessment of Performance Based Contracts

<table>
<thead>
<tr>
<th>Keeping in mind the definition of Performance Based Contracts (PES) given above, How far do you agree that PES contribute to the current practices in the following manner (If you don't have any idea on one issue, you can skip the next one)</th>
<th>I strongly Agree (5)</th>
<th>(4)</th>
<th>(3)</th>
<th>(2)</th>
<th>I strongly disagree (1)</th>
<th>Response Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>To decrease cost</td>
<td>75</td>
<td>93</td>
<td>70</td>
<td>34</td>
<td>57</td>
<td>329</td>
</tr>
<tr>
<td>To increase quality</td>
<td>111</td>
<td>83</td>
<td>67</td>
<td>24</td>
<td>52</td>
<td>337</td>
</tr>
<tr>
<td>To lead to innovative applications</td>
<td>122</td>
<td>96</td>
<td>53</td>
<td>23</td>
<td>38</td>
<td>332</td>
</tr>
<tr>
<td>To reduces workload of the authority</td>
<td>116</td>
<td>90</td>
<td>57</td>
<td>31</td>
<td>37</td>
<td>331</td>
</tr>
<tr>
<td>It is easily applicable</td>
<td>53</td>
<td>92</td>
<td>85</td>
<td>47</td>
<td>50</td>
<td>327</td>
</tr>
<tr>
<td>It is applicable only if the public employees are trained</td>
<td>205</td>
<td>81</td>
<td>24</td>
<td>8</td>
<td>14</td>
<td>332</td>
</tr>
<tr>
<td>To increase the user satisfaction</td>
<td>93</td>
<td>99</td>
<td>65</td>
<td>22</td>
<td>35</td>
<td>314</td>
</tr>
<tr>
<td>To strengthen tie between performance measurement and budget</td>
<td>91</td>
<td>92</td>
<td>55</td>
<td>25</td>
<td>34</td>
<td>297</td>
</tr>
<tr>
<td>To lead to be more performance oriented</td>
<td>121</td>
<td>110</td>
<td>45</td>
<td>14</td>
<td>26</td>
<td>316</td>
</tr>
<tr>
<td>To increase accountability</td>
<td>109</td>
<td>90</td>
<td>56</td>
<td>18</td>
<td>50</td>
<td>323</td>
</tr>
</tbody>
</table>

answered question | 349
skipped question | 277

Among the participants: about 60% supported that performance based contracting would help to reduce costs, workload, to induce innovation, and to enhance accountability; 73% supported that it would lead to be more performance oriented. Nonetheless, 86% of the participants pointed out that there was a need for technical training to apply new contracting method. Similarly, the most important problem was shared by 30% of the respondents that the performance based contracting was not seen as easily applicable. Hence, it was emphasized that performance based contracting needs a gradual transformation process let the institution accumulate knowledge and experiences (Table 6).

The final question attempted to determine how incentive/disincentive clauses affect the performance based contracting. 75% believed that the incentive/disincentive clauses make the contractor behave more innovative and increase quality, and over 65% supported that timely completion, accountability and competition would be the other benefits of these clauses.
Table 7. Assessment of Incentive/Disincentive Clauses

If the incentive and disincentive provisions to reward or penalize for meeting some specific performance thresholds were inserted to contracts, how far do you agree that the results would occur as in given below?

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>I strongly Agree (5)</th>
<th>(4)</th>
<th>(3)</th>
<th>(2)</th>
<th>I strongly disagree (1)</th>
<th>Response Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>It's easily applicable</td>
<td>102</td>
<td>89</td>
<td>60</td>
<td>40</td>
<td>39</td>
<td>330</td>
</tr>
<tr>
<td>It reduces the cost</td>
<td>94</td>
<td>93</td>
<td>62</td>
<td>38</td>
<td>26</td>
<td>313</td>
</tr>
<tr>
<td>It increases the quality</td>
<td>145</td>
<td>98</td>
<td>43</td>
<td>21</td>
<td>25</td>
<td>332</td>
</tr>
<tr>
<td>It makes the contractor behave more innovatively</td>
<td>143</td>
<td>106</td>
<td>38</td>
<td>22</td>
<td>21</td>
<td>330</td>
</tr>
<tr>
<td>It reduces workload of the authority</td>
<td>117</td>
<td>94</td>
<td>54</td>
<td>28</td>
<td>27</td>
<td>320</td>
</tr>
<tr>
<td>It helps to completion of projects on time</td>
<td>113</td>
<td>103</td>
<td>64</td>
<td>20</td>
<td>27</td>
<td>327</td>
</tr>
<tr>
<td>It increases accountability</td>
<td>115</td>
<td>98</td>
<td>54</td>
<td>16</td>
<td>33</td>
<td>316</td>
</tr>
<tr>
<td>It increases competition</td>
<td>121</td>
<td>106</td>
<td>48</td>
<td>23</td>
<td>28</td>
<td>326</td>
</tr>
<tr>
<td>It makes the contractors do high quality work</td>
<td>149</td>
<td>90</td>
<td>44</td>
<td>20</td>
<td>31</td>
<td>334</td>
</tr>
<tr>
<td>It reduces chance of legal disputes between public and private partners</td>
<td>97</td>
<td>84</td>
<td>49</td>
<td>27</td>
<td>63</td>
<td>320</td>
</tr>
</tbody>
</table>

answered question 343  
skipped question 283

4. Conclusion

This study has attempted to contribute to the debate by providing evidence regarding how KGM employees perceive and evaluate the service quality provided by their own institution; how they assess the idea of outsourcing maintenance works, and alternative contracting methods. The results revealed that KGM employees assigned good ratings to the traditional services; however, the respondents admitted that KGM might not meet the growing environmental concerns and life cycle approach demands. It is also revealed that even if the current procurement law has some advantages, it fails to meet the demand of occupational safety and quality.

Regarding to quality, the respondents were asked to evaluate the outsourcing maintenance activities which were traditionally delivered by the public sector, and it revealed that outsourcing was more likely to give savings in personnel, equipment expenses and lead to innovation and cost efficiency. Based on the definition of performance based contracting method given in the questionnaire, great majority of respondents acknowledged that the new contracting method would be beneficial in getting costs down, inducing innovation and enhancing accountability. Additionally, adding incentive and disincentive clauses to the current contracts might help to get similar benefits as in performance based contracting methods.

The findings of survey, despite having some biased responses, provide some policy implications. Gradual transformation strategy should be adopted for successful implementation of new contracting approach. Winter maintenance in a regional network where the public authority seems relatively successful could be chosen as a pilot project to be outsourced by performance based contracts. Adding incentive and disincentive clauses would be beneficial and technical details such as scope and duration of contracts might be defined based on lessons learnt process. Key policy implication is to adopt an institutional capacity building framework for performance based contracting allowing the institution to accumulate knowledge and experiences.

References
MAINTENANCE PRIORITIZATION OF ASPHALT PAVEMENTS USING TREATMENT-BASED METHODS
(CASE STUDY: MAIN ROADS OF ILAM PROVINCE, IRAN)

<table>
<thead>
<tr>
<th>TRACK</th>
<th>C.3 ROAD MAINTENANCE POLICIES AND PROGRAMS</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>AUTHOR (Capitalized Family Name)</th>
<th>POSITION</th>
<th>ORGANIZATION</th>
<th>COUNTRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHAHI DEZFOULIAN</td>
<td>1-HEAD OF TRANSPORTATION PLANNING DEPARTMENT 2-PH.D. CANDIDATE</td>
<td>1-ROAD, HOUSING &amp; URBAN DEVELOPMENT RESEARCH CENTER 2-KHAJEH NASIR TOOSI UNIVERSITY OF TECHNOLOGY</td>
<td>IRAN</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>CO-AUTHOR(S) (Capitalized Family Name)</th>
<th>POSITION</th>
<th>ORGANIZATION</th>
<th>COUNTRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGHAJANI</td>
<td>EXPERT OF MAPS AND SPATIAL INFORMATION OFFICE</td>
<td>STATISTICAL CENTER OF IRAN</td>
<td>IRAN</td>
</tr>
<tr>
<td>REZAEI</td>
<td>HEAD OF ROAD MAINTENANCE OFFICE</td>
<td>ROAD &amp; URBAN DEVELOPMENT BUREAU OF ILAM PROVINCE</td>
<td>IRAN</td>
</tr>
<tr>
<td>REZAEE ARJOODY</td>
<td>ASSOCIATED RESEARCHER</td>
<td>ROAD, HOUSING &amp; URBAN DEVELOPMENT RESEARCH CENTER</td>
<td>IRAN</td>
</tr>
<tr>
<td>E-MAIL (for correspondence)</td>
<td><a href="mailto:REZA.DEZFOULIAN@BHRC.AC.IR">REZA.DEZFOULIAN@BHRC.AC.IR</a></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

KEYWORDS:
Asphalt Pavements, Maintenance, Prioritization, Treatment-Based Methods, Iran

ABSTRACT:
The importance of pavement maintenance due to its effects on reducing the pavement deterioration rate, user/agency costs, and protection of the pavement as a national asset is quite crucial. Limitations on such issues as the financial, human, and equipment resources, other factors that affect the maintenance and treatment, and the importance of a long-term optimal planning for the pavement maintenance, all reveal the necessity of a pavement management system as the final objective of road agencies. Long-term pavement performance data and financial limitations can affect the implementation of a pavement maintenance management system and the selection of a treatment prioritization model for the pavement sections. Under conditions where such a system is in its early stages, the short-term (1 year) prioritization of treatment and maintenance plans can play important roles in road agencies’ approaches and managerial decision makings. Based on what was stated, this paper presents a short-term maintenance management approach considering the treatment-based method (a first generation prioritization method) wherein prioritization is based mainly on the type of treatment and traffic range; in fact, maintenance activities hierarchy and road type are the bases for prioritization. While doing a general evaluation of the surface distress, in this paper the importance of road type (wide main road, ordinary main roads, freeway and expressway) has been combined with the traffic range to develop the method; furthermore, crack sealing, patching, and thin overlay have been considered as maintenance activities. To check the results of the proposed method, the surface distress of flexible pavements in Ilam province, Iran, were investigated in 2013 through rapid visual evaluations.
Maintenance Prioritization of Asphalt Pavements Using Treatment-Based Methods  
(Case Study: Main Roads of Ilam Province, Iran) 

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1 INTRODUCTION 

The road network is considered as an important national asset, the preservation and maintenance of which is a necessity. Essentially, a comprehensive and optimal maintenance planning necessitates the appropriate plan for implementation, a thorough knowledge of the past, present, and future pavement data, plus considering the effective factors, user/agency cost estimates, and other costs resulted from pavement maintenance/lack of maintenance; obviously, achieving this goal requires enough time and budget. If such needs are not thoroughly met, a simplified model (based on the present pavement condition plus traffic), with no complicated optimization methods, can play an effective role in making short-term (1-year) management decisions for the maintenance prioritization of road sections. Effort has been made in this paper to propose a 1-year plan for the maintenance prioritization of Ilam province (Iran) network of main roads, based on a simple, developed, treatment-based (first generation prioritization) method considering insufficient necessary data and impracticability of the implementation of pavement management. 

2 LITERATURE REVIEW 

The Pavement Management System (PMS) is an integrated systematic method for the selection of the treatment and maintenance necessities, determination of the priorities, and the optimum treatment time through predicting the future pavement conditions (Shahin 2005). In other words, PMS is a systematic approach consisting of such different activities as the evaluation of the pavement performance, estimation of the treatment and maintenance requirements, optimization of the interests, and timely maintenance and prioritization of the sections considering the available resources and maintenance methods; PMS is the collection of all these activities (Shah et al 2013). So far, extensive PMS researches have been done through methods ranging from simple ranking to complex optimization methods. Studies show that software such as HDM-4 and MicroPaver have been used for pavement maintenance management (Fakhri and Rooeinbakht 2004), (UI-Islam and Tsunikawa 2004), (Tighe et al 2004), (Aminiet al 2012), (Fakhri and Hesari 2008). In many studies, the use of soft computing, expert system, Delphi and multi-criteria decision-making methods have been observed (Abo-Hashema and Sharaf 2004), (Chen Chen et al 2004), (Zang and Ahson 2004), (Panagopoulou and Chassiakos 2012), (Ismail et al 2009), (Fakhri and Sayedalhoseineem 2008), (Wang and Qiang 2008), (Shah et al 2013), (Shah et al 2014), (Khademi and Sheikholeslam 2010). Also, the objective functions, optimization methods (life cycle cost analysis) and performance prediction models (probabilistic and deterministic) are complex methods that have been used widely (Zheng and Flintch 2008), (Bekhet et al 2008), (Ouyang and Madanat 2004), (Kenneth and Kuhn 2012), (Heravi and Esmaeeli 2014), (Gao and Zhang 2013), (Golroo and Tighe 2009), (Wu and Flintsch 2009), (Tabatabae and Ziyadi 2013), (Henning 2008), (Menese and Ferreira 2013), (Ammar et al 2013), (Zongzhi and Madanu 2009), (Zhang and Gao 2013). 

3 PAVEMENT DETERIORATION 

Road pavements have a defined life-cycle meaning that they deteriorate in the course of time; the deterioration process continues until maintenance interventions applied to remove the defectiveness. The cycle is repeated until the road nears the end of its planned service life (known as terminal serviceability) when it is reconstructed. Maintenance intervention postpones the rate of total failure until the pavement reaches the end of its design life. 

3.1 REASONS FOR PAVEMENT DETERIORATION 

The effects of environmental factors, passing traffic, materials and construction qualities, design standards, and age of the pavement are among the reasons for pavement deterioration (Boamah2010).
4 OBJECTIVES OF PAVEMENT MAINTENANCE

Maintenance reduces the rate of the pavement deterioration, lowers the vehicles’ operational costs because of the pavement improvements, can enhance safety through engineering parameters, keeps the road continuously open for the traffic use and can affect the environment (air pollution, noise and non-renewable resources).

4.1 PAVEMENT MAINTENANCE MANAGEMENT

In fact, appropriate road management makes use of different criteria to achieve goals related to reconstruction, improvement, and maintenance. Selecting between road maintenance, constructing a new road and reconstructing an older one, is possible through considering social, cultural, and political conditions in addition to using economic and engineering analysis. The important point here is the fact that managers are to be aware of the rate of effects of different maintenance approaches on the profit they gain and other social, economical, environmental, and safety costs. Activities are classified to routine maintenance (cyclic, reactive), periodic (preventive, resurfacing, overlay and pavement reconstruction), special works (emergency, winter) and development (widening, realignment and new section) (Richard et al 1998).

4.2 IMPORTANCE OF PRIORITIZATION IN PAVEMENT MAINTENANCE DECISIONS

Since maintenance activities affect work scheduling and resource allocation, the maintenance prioritization of pavement sections, which depends on various factors like pavement conditions, traffic volume, environmental effects, performance standards and financial constraints, is a necessity for the optimal use of the resources and selection of the better choices. It is very important that the pavements in a network maintain their serviceability conditions through an appropriate maintenance strategy considering resource limitations (Shah et al 2013).

4.3 PRIORITIZATION METHODS

Prioritization methods used in pavement management system have a wide range from simple methods (based on the engineering judgment) to complex network optimization techniques. These methods can be divided as 1) Ranking methods 2) Artificial Intelligence Techniques 3) Analytical Hierarchy Process 4) Optimization methods.

4.4 DIFFERENT GENERATIONS OF DECISION SUPPORT SYSTEMS

In the course of time, decision support systems have grown and become more complete and sophisticated. Their classification to first, second, and third generations is quite a normal task and depends much on their approach towards dealing with different related issues. Many prioritization management systems combine the features of the various generations, but classification, based on generation, provides an appropriate framework for the explanation of different prioritization methods (Richard et al 1998).

4.4.1 FIRST GENERATION PRIORITIZATION METHODS

The first generation decision support systems are defined with prioritization methods wherein ranking is based on the current conditions and costs. In the first generation, there is usually one treatment choice for every section, and to determine the minimum required budget, all the sections requiring treatment are listed according to their priorities. The first generation methods are discussed under the following 3 titles: 1) defectiveness index, 2) degree of defectiveness, and 3) treatment-based methods.

* Methods based on defectiveness index

In these methods, some indices are used to specify the condition of the road section. To determine the prioritization index, making use of defectiveness indices provides a mechanism that makes the combining of different defectiveness patterns possible. These indices (sometimes known as serviceability indices) are used for the selection of the type of treatment as well as the prioritization of pavement sections.

* Methods based on the degree of defectiveness

In these methods, prioritization depends on the measured defectiveness or the defectiveness rate that has exceeded the intervention level; the more is the latter, the more is the priority.

* Treatment-based methods

In these methods, prioritization is based on the type of treatment and it is assumed that there is a hierarchy between maintenance activities and their effects on the road protection. The prioritization is based on the hierarchy of maintenance activities and traffic range. An example of this is given in Table1.
Table 1. Hierarchy of maintenance activity and traffic range

<table>
<thead>
<tr>
<th>Road hierarchy</th>
<th>Traffic range (vehicle/day)</th>
<th>Surface type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Strategic roads</td>
<td>Paved</td>
</tr>
<tr>
<td>2</td>
<td>Greater than 1000</td>
<td>Paved</td>
</tr>
<tr>
<td>3</td>
<td>500-1000</td>
<td>Paved</td>
</tr>
<tr>
<td>4</td>
<td>200-500</td>
<td>Paved</td>
</tr>
<tr>
<td>5</td>
<td>Greater than 200</td>
<td>Unpaved</td>
</tr>
<tr>
<td>6</td>
<td>Less than 200</td>
<td>Paved</td>
</tr>
<tr>
<td>7</td>
<td>50-200</td>
<td>Unpaved</td>
</tr>
<tr>
<td>8</td>
<td>Less than 50</td>
<td>Unpaved</td>
</tr>
</tbody>
</table>

Hierarchy of maintenance activity

<table>
<thead>
<tr>
<th>Priority</th>
<th>Traffic Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Emergency</td>
<td>1</td>
</tr>
<tr>
<td>Cyclic drainage</td>
<td>2</td>
</tr>
<tr>
<td>Reactive Pavement work (patching, local sealing)</td>
<td>3</td>
</tr>
<tr>
<td>Periodic preventive (resealing)</td>
<td>4</td>
</tr>
<tr>
<td>Other cyclic/reactive</td>
<td>5</td>
</tr>
<tr>
<td>Overlay/reconstruction</td>
<td>6</td>
</tr>
</tbody>
</table>

(Complied from Richard et al 1998)

4.4.2 SECOND GENERATION PRIORITIZATION METHODS

The key feature of the second generation methods is that their prioritization considers the present as well as the future road conditions and costs. Here, decisions are based on the evaluation and prediction of the results found from doing/not doing the treatments determined by considering the intervention levels.

4.4.3 THIRD GENERATION PRIORITIZATION METHODS

A main element in these systems, that distinguishes them from other generations, is optimizing different choices (multiple) and analyzing the life-cycle cost of the roads’ agency and users.

5 METHODOLOGY

Going from the first to the third generation, data requirement is increased; a large road management system, with high skills and appropriate budget level, is to utilize the third generation models, but for smaller systems, such as municipalities, simpler models would suffice. In these cases, use has to be made of treatment based methods (first generation) that are capable of overcoming many of the problems caused by the “worst-first” approach (Richard et al 1998).

Due to the insufficient data, resource limitations, and lack of the records from a comprehensive pavement management system performance, this paper has evaluated the pavement surface distress in main road sections based on expert judgment. Finally, regarding the treatment-based method, effective criteria and collected data, the maintenance prioritization of the sections is done, based on their score. Also, according to Table 1, crack sealing, patching (full depth and partial depth), and thin overlay have been used as the treatment strategies. Detailed explanations are provided in the following.

5.1 DATA COLLECTION

Since the collection of detailed pavement condition data is time-consuming and extremely costly, rapid data collection has been used in this paper, based on subjective judgment. In this method, approximate extent and severity of each surface distress type can be rapidly estimated according to the rater’s judgment (Bandara and Guarante 2001). In order to evaluate the surface distress of flexible pavements, 134 pavement sections in Ilam province were inspected (92 with distress) in 2013. Factors such as traffic, age, functional classification and pavement condition were among the parameters considered in sectioning.
5.2 CRITERIA AFFECTING PAVEMENT MAINTENANCE MANAGEMENT

In prioritization of roads pavements maintenance, the following parameters (from among many) have been considered in this paper:

1) Type and hierarchy of the road: in this group, prioritization is done on arterial/non-arterial main roads such as freeways, expressways, wide main roads, and ordinary main roads. To compare the importance of the road type and its performance, expert opinions have been used in the form of different coefficients (road type weighting) as follows: freeway: 2.79, expressway: 2, wide arterial main road: 1.5, ordinary arterial main road: 1.43, wide non-arterial main road: 1.07 and ordinary main road: 1. Figure 1 shows the roads of Ilam province. Arterial (strategic) is a road with one of the following features: a) It is part of the national roads network b) It provides a corridor for the country’s entering/leaving vehicles c) It connects the centers of different provinces or large cities inside the country.

![Figure 1. Main and secondary roads of Ilam Province](image)

2) Pavement distress: information about the pavement distress and serviceability is one of the effective parameters in pavement maintenance management. Since the objective is to have a general evaluation of the pavement condition, effort has been made to evaluate the serious asphalt pavement surface distress through rapid visual evaluation, the extent and severity of the pavement distresses have been considered, based on the subjective (expert) judgment. In order to use treatment-based method; Crack sealing, patching, and thin overlay are the choices suggested as pavement treatments, also evaluated sections divided into 4 groups (codes). The section code (1, 2, 3, 4) is determined in experts’ meetings through the results of visual inspections, required treatments and defined range limits (either separately or combined); which are for a main road with a length of 1 km and 7.3 m wide. As shown below, evaluated pavement section, which has significant distresses with a high level of severity and extensive extent, is placed in the last group with code 4. It should be mentioned that treatment choices are selected based on the extent and severity of pavement distresses in each section. In general, pavement sections with more distresses have a higher maintenance priority in condition-based prioritization methods. To demonstrate and compare the importance and priority of pavement sections with different distresses, weighting factors were assigned to sections codes (1, 2, 3 and 4) based on expert opinion, which where (0, 1, 3 and 7), respectively. Because of using the treatment-based method, treatments (work type) such as reactive (crack sealing, patching), preventive and resurfacing have more priority than overlaying and pavement reconstruction. Therefore, the above mentioned weights (1, 3 and 7) should be considered in reverse order after normalization for pavement section groups. Section groups are as follows:

i) Pavement sections without distress: new construction, recent overlay; no maintenance required; shown in green in the roads network, (code 1).

ii) Pavement sections, which need less than 10% crack sealing, less than 5% partial depth patching; shown in blue in the roads network (low distress level, code 2).

iii) Pavement sections, which need crack sealing (between 10 and 30%), partial depth patching between 5 and 30% (full depth patching up to 15%), and thin overlay of up to 40%; shown in yellow in the roads network (medium distress level, code 3).

iii) Pavements sections, which need crack sealing (more than 30% crack sealing), more than 30% partial depth patching (more than 15% full depth patching), and more than 40% thin overlay; shown in red in the roads network (high distress level, code 4).

It should be mentioned that the above figures are the range limits used to simplify the recognition of the section distress, and are considered either separately or combined. In the case of substantial structural distress, thick overlay and reconstruction could be considered. Figure 2 and 3 show, as an example, the distress recorded for Ilam-Seymareh route.
97 km long with 10 sections and IlamDarreh-shahr route 105 km long, in the form of a strip map and in the GIS; strip maps have been prepared from Ilam Province communication routes based on the inspections of an expert team and their recognition of the distress. For sectioning and precise inspection, sections have been divided, into ample units; the results of pavement section evaluation have been shown in 4 groups (codes).

3) Traffic: the AADT-based passing traffic of a road is a parameter that affects the speed of the pavement deterioration; the rate of the passing traffic used in this paper has been found through the results of the traffic counters analysis at the communication routes of Ilam Province.

4) Treatment costs: estimations regarding the section treatment can be considered in the prioritization; since the economic factors are not of much interest in treatment-based methods, they have been neglected in this study as well. The author will study the issue and present the results in future papers.

6 OUTPUT OF THE PROPOSED METHOD AND DISCUSSION

The treatment-based method is a short-term (1-year) planning method which is not strictly based upon economic criteria, wherein prioritization is done through the road hierarchy (traffic), and considering the required treatments (crack sealing, patching, etc.). In this paper, the pavement sections have been prioritized based on some patterns from aforesaid method. Since some of the roads were arterial/strategic on which traffic exceeded 1000 vehicles/day, the type and performance level of the road plus its traffic was considered as one combinatorial factor. The section distress (treatment needed) is considered as another factor to simplify the prioritization of the selected sections in the proposed method. It is worth mentioning that weights of the above two factors were considered to be 0.67 and 0.33 (weighting factors) respectively based on the designed questionnaire and expert opinion. Table 2 shows an example of the prioritization of 92 studied section (9 sections have been shown). In this table, data on each section have been shown briefly and the final prioritization is based on section score (C2). In order to clarify the proposed method, first row with highest score (the first priority) is explained. The first column shows the rank of each section which is placed in a specified route name (C3). Because of the road type (expressway) and its performance (arterial) the coefficient of “2” is used in column 6. In the seventh column, the section code is shown. In other words the pavement section with a length of 1600 m (C4) has low distress level. In general, coefficient of “1” in the eighth column (C8) shows the lowest maintenance priority because of the low distress level (code 2). As described in the previous sections, because of the usage of treatment-based method, (used in this paper), this value (1) is used in reverse order after normalization (C11) for aforesaid section (more priority). The values of the other columns are presented at the bottom of the table. In this paper, factors such as traffic, road type and its performance and required treatment options, were combined through some pattern from the treatment-based method and it is extended in the framework of the proposed method. The results of the following table can be used as a scenario for pavement maintenance prioritization. Budget
constraint is an important factor, which can affect maintenance prioritization. Finally, maintenance prioritization of about 70 percent of sections was done based on available budget of Ilam province from the highest to lowest rank in the first year.

Table 2. prioritization of 92 studied sections

<table>
<thead>
<tr>
<th>(C1)</th>
<th>(C2)</th>
<th>(C3)</th>
<th>(C4)</th>
<th>(C5)</th>
<th>(C6)</th>
<th>(C7)</th>
<th>(C8)</th>
<th>(C9)</th>
<th>(C10)</th>
<th>(C11)</th>
<th>(C12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.020</td>
<td>Ilam-Ghalageh</td>
<td>1600</td>
<td>Y</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>5700</td>
<td>0.0135</td>
<td>0.0205</td>
<td>0.0207</td>
</tr>
<tr>
<td>10</td>
<td>0.016</td>
<td>Seymreh bridge-Shabodagh</td>
<td>7400</td>
<td>Y</td>
<td>1.5</td>
<td>2</td>
<td>1</td>
<td>5000</td>
<td>0.0118</td>
<td>0.0205</td>
<td>0.0136</td>
</tr>
<tr>
<td>17</td>
<td>0.015</td>
<td>Ilam-Darreshahr</td>
<td>2100</td>
<td>N</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>6700</td>
<td>0.0159</td>
<td>0.0205</td>
<td>0.0122</td>
</tr>
<tr>
<td>31</td>
<td>0.012</td>
<td>Ilam-Ghalageh</td>
<td>5400</td>
<td>Y</td>
<td>1.5</td>
<td>3</td>
<td>3</td>
<td>5700</td>
<td>0.0135</td>
<td>0.0068</td>
<td>0.0155</td>
</tr>
<tr>
<td>49</td>
<td>0.010</td>
<td>Mehran-serahikaver</td>
<td>2200</td>
<td>Y</td>
<td>1.5</td>
<td>2</td>
<td>1</td>
<td>1800</td>
<td>0.0043</td>
<td>0.0205</td>
<td>0.0049</td>
</tr>
<tr>
<td>60</td>
<td>0.009</td>
<td>Ilam-Ghalageh</td>
<td>3400</td>
<td>Y</td>
<td>1.43</td>
<td>4</td>
<td>7</td>
<td>4900</td>
<td>0.0116</td>
<td>0.0029</td>
<td>0.0127</td>
</tr>
<tr>
<td>69</td>
<td>0.008</td>
<td>Ilam-Mehran</td>
<td>5200</td>
<td>Y</td>
<td>1.43</td>
<td>3</td>
<td>3</td>
<td>3700</td>
<td>0.0088</td>
<td>0.0068</td>
<td>0.0096</td>
</tr>
<tr>
<td>85</td>
<td>0.004</td>
<td>Dehloran-Serahikaver</td>
<td>400</td>
<td>Y</td>
<td>1.43</td>
<td>4</td>
<td>7</td>
<td>1800</td>
<td>0.0043</td>
<td>0.0029</td>
<td>0.0047</td>
</tr>
<tr>
<td>92</td>
<td>0.003</td>
<td>Dehloran-Andimeshk</td>
<td>4800</td>
<td>N</td>
<td>1</td>
<td>4</td>
<td>7</td>
<td>1700</td>
<td>0.0040</td>
<td>0.0029</td>
<td>0.003</td>
</tr>
</tbody>
</table>

In the above table the columns are as follows:

- C1: Rank
- C2: Section score
- C3: Route name
- C4: Section length (m)
- C5: Arterial (Y/N)
- C6: Road type weight
- C7: Section code (2,3,4)
- C8: Weighting factors
- C9: Traffic/AADT
- C10: Traffic (Normalized AADT)
- C11: Reverse-Normalized C7
- C12: The combination of traffic and road type

7 CONCLUSIONS

In this study, the objective has been to propose a model for a short-term (1-year) prioritization, maintenance management, and treatment of Ilam Province (Iran) main roads network. Definitely, the implementation of the Pavement Management System (PMS) can play vital role in the optimal maintenance planning. To develop and complete the proposed method, the author is working on supplementary papers through considering such factors as the treatment costs, pavement evaluation index, and developing appropriate deterioration models that will considerably enhance the implementation of the PMS in Iran. Results found from using the method show that although a large organization (such as the Ministry of Road and Transportation), with its high capabilities and enough budgets, needs to apply PMS, it is possible, considering the existing conditions, to use simpler methods for smaller organizations for the prioritization of roads maintenance. In such cases, the use of treatment-based methods (first generation) can overcome many problems resulted from the worst-first approach.

8 ACKNOWLEDGEMENTS

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Local Asset Management Guidelines

Guideline on the Application of the ISO 55001 standard (for Asset Management) in Abu Dhabi, United Arab Emirates

Issue Date:  September 2015

Presenting Speaker:  Alan Roland
Other Authors:  Enda McDonnell
                Frank Ciampa
Table of Contents

1 Background & Introduction .................................................................................................................. 1
  1.1 About The Abu Dhabi Quality and Conformity Council ................................................................. 1
  1.2 Asset Management Working Group .............................................................................................. 1
  1.3 Importance for Abu Dhabi ............................................................................................................ 2

2 Objectives.............................................................................................................................................. 2

3 Proposed Solutions .................................................................................................................................. 3

4 Solution Implementation .......................................................................................................................... 5
  4.1 Getting Started ............................................................................................................................... 5
  4.2 Strategy & Planning ......................................................................................................................... 5
  4.3 Decisions & Accountability ............................................................................................................. 6
  4.4 Asset Information ........................................................................................................................... 6
  4.5 Organization & People .................................................................................................................... 6
  4.6 Risk & Review ............................................................................................................................... 7
  4.7 Elements for Consideration in Abu Dhabi ..................................................................................... 7

5 Evaluation of Results and Next Steps .................................................................................................... 7

6 Acknowledgements .................................................................................................................................. 8

List of Tables

TABLE 1 - COMPARISON BETWEEN ISO 55001 AND PAS 55 ............................................................ 3
TABLE 2 – MEMBERS OF QCC WORKING GROUP .............................................................................. 8
1 Background & Introduction

1.1 About The Abu Dhabi Quality and Conformity Council

Abu Dhabi city is the largest city in the UAE and in Abu Dhabi Emirate. The city has developed a tremendous amount since the discovery of oil in the mid-20th century. Now, it has become one the most developed and renowned cities in the world. The number of developments in Abu Dhabi city is continuously increasing in response to population growth and economic development.

The Abu Dhabi Quality and Conformity Council (QCC) was established by Law No. 3 of 2009, issued by His Highness Sheikh Khalifa Bin Zayed Al Nahyan, President of the UAE. The QCC is responsible for the development of Abu Dhabi Emirate’s Quality Infrastructure, which enables industry leaders and regulators to ensure that products, systems, and personnel may be rigorously tested and certified according to UAE and International Standards.

<table>
<thead>
<tr>
<th>Vision:</th>
<th>Developing Abu Dhabi’s Quality Infrastructure to enable global distinction of the Emirate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission:</td>
<td>To lead, facilitate and develop an efficient, effective and globally integrated quality infrastructure in Abu Dhabi that promotes a culture of quality, enhances industrial development and competitiveness, as well as ensures consumer safety.</td>
</tr>
<tr>
<td>Values:</td>
<td>- Transparency: Motivated to present clear messages without influence from hidden agenda.</td>
</tr>
<tr>
<td></td>
<td>- Goal orientation: Committed to overcoming all obstacles to achieve objectives.</td>
</tr>
<tr>
<td></td>
<td>- Initiative: Willing to take the first step and seek alternatives if the course of action requires.</td>
</tr>
<tr>
<td></td>
<td>- Innovation: Driven to embrace alternative solutions to challenges and to implement creative ideas.</td>
</tr>
<tr>
<td></td>
<td>- Commitment: Individual sense of responsibility, obligation and attachment to QCC, and the sincere desire to deliver work at the highest levels of professionalism.</td>
</tr>
</tbody>
</table>

1.2 Asset Management Working Group

The QCC Working Group for Asset Management was established in July 2012 in under the leadership of His Highness Sheikh Khalifa bin Zayed Al Nahyan, President of the UAE and Ruler of Abu Dhabi, and His Highness Sheikh Mohamed bin Zayed Al Nahyan, Crown Prince of Abu Dhabi, Deputy Supreme Commander of the UAE Armed Forces and Chairman of the Abu Dhabi Executive Council. The purpose of the working group was created in order to review existing international standards for Asset Management and draft an Emirate-wide regulatory framework specific to conditions and requirements in Abu Dhabi.
Asset Management, in this context, is defined as the best practices that regulate a sustainable life cycle of all types of assets including physical infrastructure assets (e.g., roads, bridges, parks, utilities, buildings, etc.). It also includes the management of related fields, such as the human resources, information, finances, and performance associated with physical assets.

Membership of the Working Group is well-represented by entities with a stake in sound asset management practices, which includes, in part, the following:

- Emirate of Abu Dhabi Department of Municipal Affairs (DMA), which plays a key role in the planning, management and protection of infrastructure assets in the Emirate.
- Abu Dhabi Education Council (ADEC), who provides oversight for asset management activities spanning 448 schools (265 public and 183 private).\(^1\)
- Abu Dhabi Urban Planning Council (UPC) that manage the structured process for the planning, implementation and development of area plans and infill developments.
- Abu Dhabi Department of Transportation (DoT) that manage over 12,000 lane.km of external roads (i.e., connecting different parts of the Emirate) and over 16,800 km of internal road network.
- Abu Dhabi Transmission & Despatch Company (TRANSCO), which is responsible for the safe, secure and reliable transmission of water and electricity to national utility distributors.

A full list of participants is provided for reference in Table 2.

1.3 Importance for Abu Dhabi

Under its great leadership, the Abu Dhabi Government has invested heavily in the infrastructure of Abu Dhabi, and continues to do so. Consequently, the introduction and practice of Asset Management in Abu Dhabi is paramount, and continues to be refined in order to preserve past investments and ensure competitiveness and sector-specific production within the Emirate of Abu Dhabi.

As such, the combined efforts of multiple government entities have created an Abu Dhabi Guideline, which provides guidance on the Application of the ISO 55001:2014 standard (Asset management -- Management Systems -- Requirements) in the UAE. QCC policy encourages the use of UAE national standards published by the Emirates Authority for Standardization and Metrology (ESMA)\(^2\). Accordingly, in the field of Asset Management, the Abu Dhabi Guideline recommends the application of the ISO 55000 suite of standards, which are high-level international documents that have superseded forerunner documents like the PAS 55 series.

2 Objectives

The Working Group identified that there was an opportunity to develop a guideline for the application of the ISO 55000 suite of standards at local level. Also, that such a guideline could be accepted at local,

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1 “The Customer Service Journey” presentation by ADEC
2 ESMA is the National Standards Body of the UAE and part of the regional (GSO—the GCC Standardization Organization) & international standards system
national, and perhaps even at regional level as a valuable guidance assist to implementation of best practices in Asset Management.

As such, QCC Working Group set out to develop an Abu Dhabi Guideline (ADG) with a view that:

- Provides specific guidance for the implementation of asset management systems similar to the PAS 55 standard currently used by many Abu Dhabi entities but complying with the new ISO 55000 series;
- Updates the specific recommendations in PAS 55 to reflect the recent improvements in Asset Management practices (including the release of ISO 55000 series of standards); and
- Recommends specific guidance that reflects local conditions in the Emirate of Abu Dhabi.

Following local adoption, it is possible that the ADG may be raised to national level as a draft UAE national standard; hopefully, to be published as a UAE national standard by ESMA and then perhaps accepted at the Gulf Cooperative Council (GCC) level by GCC Standardization Organization (GSO) as a valuable guidance tool to assist in the implementation of Asset Management best practices throughout the region.

3 Proposed Solutions

The QCC Asset Management Working Group began the process with the vision to provide entities in Abu Dhabi with a bridge to transition from PAS 55 to the superseding ISO 55000. The British PAS 55 series of standards were used as a basis for the ISO 55000 standards that were published in January 2014, along with other national and international documents and manuals (Australian and New Zealand publications were also influential in shaping the current standards of Asset Management). As such, PAS 55-1: 2008 and PAS 55-2: 2008 were among the precursors and forerunners of the ISO 55000 series. Abu Dhabi organizations have used the PAS 55 standards as references for their Asset Management journey. Some have targeted achieving certification that conforms to these standards as part of their process.

The Working Group made an effort to compare the relevant sections of ISO 55001 with the corresponding clauses of PAS 55, which is presented in Table 1. This outline is intended to further an organization’s understanding of the current requirements in context to superseded guidance.

<table>
<thead>
<tr>
<th>ISO 55001</th>
<th>PAS55: 2008</th>
<th>Section of the ADG Document</th>
</tr>
</thead>
<tbody>
<tr>
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<td>No Specific Clause</td>
<td>6.1 Understanding the Organization &amp; Its Context</td>
</tr>
<tr>
<td>4.2 Understanding the Needs and, Expectation of Stakeholders</td>
<td>4.4.8 Legal and Other Requirements</td>
<td>11.9 Understanding the Needs and Expectations of Stakeholders</td>
</tr>
<tr>
<td>4.3 Determine the Scope of the Asset Management System</td>
<td>No Specific Clause</td>
<td>6.3 Determining the Scope of Asset Management</td>
</tr>
<tr>
<td>4.4 Asset Management System</td>
<td>4.1 General Requirements</td>
<td>6.3 Determining the Scope of Asset Management</td>
</tr>
<tr>
<td>5.2 Policy</td>
<td>4.2 Asset Management Policy</td>
<td>7.2 Asset Management Policy</td>
</tr>
</tbody>
</table>
In addition to the roadmap for transition from PAS 55 to ISO 55000, the Working Group relied on input from a variety of different stakeholder entities that comprise its membership to identify elements that are particularly relevant to Abu Dhabi. Specifically, brief guidance was created on the subjects of Asset Transfer, Asset Valuation & Useful Life, Institutional Reforms & Capacity Building, Adoption of Emirate-Wide & Entity-Specific Policies, as well as Regulatory Requirements relevant for asset management in Abu Dhabi.
To provide further local context, two case studies were appended to the ADG. The first case study showcased the asset management milestones achieved by TRANSCO, who have received the International Accreditation of Asset Management (ISO 55000) in 2014, after being previously certified to PAS 55. The second case study was related to the ongoing asset management journey of the DMA, who have established a clear ‘Municipality Asset Management Roadmap’ to achieve its vision for asset management. The DMA have the ultimate goal of achieving ISO 55000 certification, and serve as a model for organizations that are just beginning to identify asset management practices as a priority in their respective organizations.

4 Solution Implementation

The general outline of the document followed the process of implementing asset management in accordance with the theme of ISO 55000. Subject areas are listed below, and briefly outlined with select extractions in the following sections.

- Getting Started;
- Strategy & Planning;
- Decisions & Accountability;
- Asset Information;
- Organization & People;
- Risk & Review; and
- Elements for Consideration in Abu Dhabi.

For each of the respective sections, the QCC Asset Management Working Group aimed to include subsections that provided “Purpose”, “Guidance”, “Advisory”, and where applicable “Examples”.

4.1 Getting Started

Clear direction, commitment, and leadership within an organization are essential enablers of good asset management. Leaders of an organization must demonstrate a commitment to the ISO 55000 standard by clearly defining its guiding principles, the criteria to be used for informing the decision-making process, requirements for reporting in line with ISO 55001, and requirements for a process to facilitate continual improvement.

4.2 Strategy & Planning

The following is an example of an Asset Management Policy Statement from the Abu Dhabi Department of Municipal Affairs:

*Asset Management is a broad strategic framework that encompasses many engineering, project management, and administrative disciplines and involves the entire Emirate’s Municipal System. The terms Asset Management, as used in this document, are defined as “the application of sound technical, social, and economic principles that considers present and future needs of users, and the service from the asset”. To guide the Municipal System, the following policy statements have been developed:*
• Each Municipality within its jurisdiction will maintain and manage infrastructure assets at defined levels to support public safety, community well-being, and customer and community goals.

• Each Municipality within its jurisdiction will monitor standards and service levels to ensure that they meet/support customer and community and Municipal System’s goals and objectives.

• Each Municipality within its jurisdiction will develop and maintain asset inventories of all its infrastructures.

• Each Municipality within its jurisdiction will establish Asset Management Plans (AMPs) including infrastructure replacement strategies through the use of full life cycle costing principles.

• Each Municipality within its jurisdiction will plan financially for the appropriate level of maintenance of assets to deliver service levels and extend the useful life of assets.

• Each Municipality within its jurisdiction will plan for and request stable long term funding to replace and/or renew and/or decommission infrastructure assets.

• Each Municipality shall program rolling 5-Year OPEX plans consistent with the AMPs and financial requirements.

• Each municipality within its jurisdiction will report to DMA regularly on the status and performance of work related to the implementation of this asset management policy.

4.3 Decisions & Accountability

Operational planning and control is a key aspect of “life cycle” asset management that ensures holistic stewardship over the creation/acquisition, utilization, maintenance, and renewal/disposal of a physical asset.

4.4 Asset Information

The organization should determine processes for managing asset information over its life cycle from identifying information needs, planning, acquiring information, maintenance, deployment and finally archival and disposal of information.

4.5 Organization & People

The organization should ensure that all employees who have been assigned asset management roles and responsibilities are aware of the importance, are adequately trained, and are competent to discharge their responsibilities. This is critical for the successful delivery of the asset management strategy and achievement of asset management objectives.
4.6 Risk & Review

Nonconformities (including failures) can occur in its assets, and asset management activities. Processes and procedures must be implemented by an organization to identify and correct any non-conformities. Corrective actions are actions taken to address the root cause(s) of identified non-conformances, or incidents, in order to manage their consequences, and to prevent or reduce the likelihood of recurrence.

4.7 Elements for Consideration in Abu Dhabi

Asset valuation must account for buildings, land, etc. in a consistent manner. Additionally, valuation must provide clarification that contract value or reimbursement value of various assets can, and often does, differ from the book value on accounts when an asset is taken over by entity after transfer.

As of April 2015, the Abu Dhabi Department of Finance (DoF) is in the process of preparing an Emirate-wide Asset Valuation Policy that will be aligned with Generally Accepted Accounting Principles. These will set the methods and procedures to be used by all entities in charge of government assets for their valuation.

The Asset Useful Life is an important step in the asset valuation work. The DoF has established asset useful life criteria for all types of infrastructure, and has carried out an integration of these criteria into their Accrual Accounting System.

Once these policies are fully implemented, they shall be considered in conjunction with the guidance provided here, and in accordance with relevant government instructions/decrees/decisions.

5 Evaluation of Results and Next Steps

It has been identified that organizations in the Emirate of Abu Dhabi are not well suited to easily adopt Asset Management, at present. This is because many organization structures currently deviate from those required for compliance with asset management standards. Changes in organization structures would allow for gradual adoption of asset management principles, but such changes can often take long periods of time to fully implement.

Similarly, while the structure of the organization itself must evolve to align with asset management principles, so too must the knowledge and understanding of the principles held by the people that make up the organization. Education and awareness programs would certainly help to expose more individuals to asset management principles; thereby, helping to build capacity overall.

The ADG should help to address some of these items, while increasing capacity of asset management concepts throughout the Emirate. It is intended to be used as a tool for a variety of entities; from those that have already established asset management to those that are formalizing asset management for the first time.
6 Acknowledgements

The membership of the QCC Working Group is presented in

<table>
<thead>
<tr>
<th>Name</th>
<th>Entity</th>
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<tbody>
<tr>
<td>1 Abdulhafidh Ahmed Alzbeidi</td>
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<td>6 Akli Ourad</td>
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<td>Abu Dhabi Department of Transportation (DoT)</td>
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<td>Musanada</td>
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<td>ADEC</td>
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<td>15 Mahmood Al Marzouqi (Chairman)</td>
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<td>21 Salem Al Mazrouee</td>
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<td>22 Salma Al Ali</td>
<td>ADDC</td>
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<td>23 Shareefa Al Marzouqi</td>
<td>TRANSCO</td>
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<tr>
<td>24 Syed Akhlaq</td>
<td>ADSSC</td>
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In addition to the QCC Working group, acknowledgement should be extended to the British Standards Institution (BSI), who provided great support for the culmination of the ADG. This is a true manifestation of the good intentions coming from the terms of the Memorandum of Understanding between QCC and BSI.

Other general support was provided by ESMA, who remains a local partner for the QCC in the UAE.
# Development of Pavement Serviceability Models for Urban Roads: The Colombian Case

<table>
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</table>

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**KEYWORDS:**

Serviceability, PSI, International Roughness Index, IRI, Urban roads.

**ABSTRACT:**

One key aspect in the design and maintenance of pavements is the evaluation of the functional and structural integrity of the current and future condition of the road surface. A pavement must guarantee safe operations to its users, therefore it is essential to define and implement a methodology to assess its performance. The serviceability is a concept generally used by the pavement engineering community to assess the overall condition of a pavement structure; it quantifies the ability of a specific pavement section to serve traffic in its current condition. The serviceability of a road represents the quality of the road surface as perceived by users; hence it is associated with different distresses of the road surface. Pavement serviceability models have been developed to predict user perception of a specific road based on its distinctive distress types. However, the validity of such models is based on the users ability to subjectively assess the functional condition of a road surface. Furthermore, one can expect these models to be sensitive to the sociocultural characteristics of the environment in which they were developed; therefore, the application of these models can be questioned in a country with different types of users. Moreover, the serviceability models available on the literature are generally applicable to interstates and rural roads. In addition, different investigations have shown that road users in developing countries have higher tolerance toward accepting pavement in poor conditions, hence the present investigation aimed to develop serviceability models that incorporate the sociocultural characteristics of Colombian road users.

More than a hundred (100) pavement sections with different surface characteristics were evaluated. Performance indexes such as the International Roughness Index (IRI) and the Pavement Condition Index (PCI) were determined on each pavement section. Multiple Linear Regression, exponential and power models were developed to correlate the pavement performance indicators with the assessment made by users on each pavement section. Moreover, it was seen that Colombian users have higher tolerance toward roads with high IRI values in urban roads; this could be explained given that the operational speed on these roads is significantly lower that the 80km/h defined by the traditional IRI model. Threshold limits for the acceptance of the IRI were also defined.

Finally, the models developed on the present investigation could be used as an effective and objective instrument to assist the maintenance & rehabilitation decision making process; saving time and money on public investment, and thus achieve an increase in the welfare of the urban population of Colombia.
Development of Pavement Serviceability Models for Urban Roads: The Colombian Case

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INTRODUCTION

Road infrastructure is a key element that conditions economic growth, tourism and social development of communities and citizen welfare. In a city, a well-designed road network creates, stimulates and guarantees positive synergy and enhances social cohesion and integration by giving its users the possibility to access to any given site at reduced time (Fan and Chan-Kang, 2005). In all regional and urban levels, adequate road infrastructure provides an open door to progress.

A competitive city will destine a suitable investment to road infrastructure, guarantying that it is executed in accordance with the macro policies of reorganization in order to enhance its growth. However, agencies should not only define investment funds for the construction of new road projects, but also secure resources for the maintenance of the existing network (Fuentes et al, 2012).

Pavements tend to deteriorate very slowly during the first years after initial construction; however, these tend to deteriorate rapidly after aging. Agencies in charge of road infrastructure must establish a Pavement Management System (PMS) to guarantee the sustainability of the road network. Programming timely preventive maintenance activities will prolong the life of pavements by reducing their rate of deterioration. These activities have proven to be cost effective and improve the life quality of citizens.

All the above issues highlight the need for a PMS that supports the decision-making process with regard to road infrastructure; however, for this it is necessary to define an appropriate index to assess the current state of a pavement structure. The serviceability is a concept generally used by the pavement engineering community to assess the overall condition of a pavement structure; it quantifies the ability of a specific pavement section to serve traffic in its current condition. The serviceability of a road represents the quality of the road surface as perceived by users (comfort); hence it is associated with different distresses of the road surface.

The International Roughness Index (IRI), which is used to evaluate road roughness, is one of the most common indicators for characterizing road surfaces with respect to user comfort. Several models are available in the literature that relate the IRI to the Present Serviceability Index (PSI) (Paterson (1987), Janoff (1988), Al-Omari and Darter (1994), and Hall and Munoz (1999)). However, these mathematical models are generally developed with reference to rural roads and their application in urban areas is often questionable (La Torre, et al, 2002).

OBJECTIVES

The present investigation aims to explore the relationship between the subjective serviceability pavement parameters and objective parameters measured on urban roads sections located in Colombia; hence incorporating specific characteristics of Colombian road users into the serviceability models.
The primary objective of this research is to develop a predictive model that correlates pavement serviceability with two objective pavement indexes such as the Pavement Condition Index and International Roughness Index, for the context of urban roads.

**PREVIOUS PAVEMENT SERVICEABILITY MODELS**

The first pavement serviceability model was introduced in 1958 by the AASHO Road Test research staff (AASHO, 1962). Carey, W. N., and P. E. Irick, 1962, used different distress indicators to predict pavement serviceability; however, they found that pavement roughness was the primary factor that conditioned the PSI.

Several studies have been conducted since that time that associate pavement condition indicators to the PSI (Nair, et al., 1985). Researchers such as Paterson (1987), Janoff (1988), Al-OMari and Darter (1994), and Hall and Munoz (1999), proposed serviceability models that used the IRI as the primary independent variable. These models were developed for rural roads.

Solminihac et al, (2003), showed that prediction of serviceability was quite accurate based on IRI, when compared to previous studies; and also concluded that road users in developing countries are more tolerant to pavement surfaces in poor conditions. On the other hand, La Torre et al, (2002), suggested that the conventional IRI is not suitable for urban roads, and should not be considered in serviceability models. La Torre et al, (2002), based their conclusions on a study that included 17 different pavement sections.

**RESEARCH APPROACH**

In order to achieve the objectives proposed in this investigation, it was first necessary to select a sufficient number of pavement sections, covering a wide range of possible surface conditions. More than a hundred (100) pavement sections with different surface characteristics were evaluated across the city of Barranquilla, Colombia.

Performance indexes such as the International Roughness Index (IRI) (ASTM E1926 – 08) and the Pavement Condition Index (PCI) (ASTM D6433 – 11) were determined on each pavement section. Pavement profiles were measured using a SurPro (Nazef et al, 2008). Figure 1 illustrates the profilometer.

![Figure 1. SurPro Profilometer.](image-url)
To evaluate the drivers’ rating on different pavement sections, an extensive survey has been carried out on each of the pavement sections. The people that made up the evaluation panel was one of the most important aspects in this study, they had to represent the public which generally circulates on the city’s streets, hence, public and particular drivers were included in the panel. It is important to note that each participant drove on its own vehicle over the pavement section in order to assess its condition. At least 15 surveys were taken on each pavement section.

Participants were trained so that they could recognize and better assess the condition of a pavement section. Interviewers were also trained so that they could address any concerns that could result from the process associated with the rating form. A revised version of the widely used AASHTO scale was used to capture driver’s perception. Figure 2 illustrates the rating form used.

Participants were asked to rate how comfortable they feel traveling along the road section on a scale of 1 to 5, where 1 is very bad and 5 is very good. The ratings were then used to calculate the Pavement Serviceability Index (PSI) according to the following equations:

1. PSI = 5e^{-0.078 \cdot IRI}
   \[ R = 0.4925 \]

2. PSI = 9.58e^{-0.17 \cdot IRI}
   \[ R = 0.7266 \]

The data collected was compiled in a database that includes PCI, IRI, PSI, and other physical characteristics of pavement such as, pavement type, section length and others. Figures 3, 4 and 5 illustrate the relationship among the variables.

Figure 3 depicts the relationship between the International Roughness Index and the Present Serviceability Index. It is observed that the serviceability decreases as the IRI increases.

![Figure 3 Relationships between PSI and IRI](image-url)
Two exponential models were proposed to describe the IRI-PSI relationship. The first model, represented by Equation (1) in the Figure 3, is constrained to provide a maximum PSI of 5 when the IRI is 0. The second model, represented by Equation (2) in the Figure 3, provides best data fit but it doesn’t have a sound interpretation when the IRI = 0.

\[
PSI = 5 \times e^{-0.078 \times IRI} \tag{1}
\]

\[
PSI = 9.58 \times e^{-0.17 \times IRI} \tag{2}
\]

Where the IRI is express in m/km.

From Figure 3 one can observe that the IRI values evaluated are significantly elevated; this is explained by the particular characteristics of urban road in Colombia, where pavement roughness is mainly defined by the natural topography of the terrain. The above can be used to explain the parameters obtained on Equation (2).

Furthermore, Figure 4 illustrates the relationship between the International Roughness Index and the Pavement Condition Index. It is observed that the PCI decreases as the IRI increases. In addition, Figure 5 illustrates the relationship between the PCI and the PSI.

**Figure 4 Relationships between PCI and IRI**

**Figure 5 Relationships between PSI and PCI**
Equation (3) presents an exponential model that can be used to describe the IRI-PCI relationship. Equation (4) represents a power regression model that can be used to describe the PSI-PCI relationship.

\[
PCI = 133.84 \times e^{-0.133 \times IRI} \tag{3}
\]

\[
PSI = 0.5682 \times PCI^{0.4384} \tag{4}
\]

Where the IRI is expressed in m/km.

Moreover, Equation (5) presents a linear regression model that uses both IRI and PCI as explanatory variables to predict the PSI.

\[
PSI = 3.7 - 0.178 \times IRI + 0.0145 \times PCI \tag{5}
\]

Where the IRI is expressed in m/km. The coefficient of determination (R^2) for this model was 60.72%.

Finally, Table 1 summarizes the information associated with the distress indicators, and includes the evaluation of the level of acceptability of the users to the road condition. Table 1 suggests that Colombian road users have a higher tolerance to typical high IRI values. It is seen that 50% of the users accept a road with an IRI of 6.22 m/km, a value that is considered poor by international standards (Sayers et al. 1995, and Shafizadeh, K and Mannering, F, 2002).

Table 1 Acceptability of road users associated to different distress indicators

<table>
<thead>
<tr>
<th>% Users Satisfied</th>
<th>PSI</th>
<th>IRI (m/km)</th>
<th>PCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td>4.91</td>
<td>3.93</td>
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<td>50</td>
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<td>6.22</td>
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<tr>
<td>25</td>
<td>3</td>
<td>7.12</td>
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CONCLUSIONS

In this study, more than a hundred (100) pavement sections with different surface characteristics were evaluated. Performance indexes such as the International Roughness Index (IRI) and the Pavement Condition Index (PCI) were determined on each pavement section. In addition, road users were placed in real world driving scenarios and asked to reveal their opinion about the condition of selected pavement sections.

Models were proposed that enable one to predict pavement serviceability based on both IRI and PCI. A mathematical model relating IRI with the PCI was also developed. It was found the IRI is a key parameter that determines pavement serviceability. Results also suggest that Colombian users have higher tolerance toward roads with high IRI values in urban roads; this could be explained given that the operational speed on these roads is significantly lower than the 80km/h defined by the traditional IRI model. Furthermore, threshold limits for the acceptance of the IRI were also defined.

Moreover, it was seen that the PCI also influences the serviceability index. A road user is not only conditioned by what he experiences while driving over a pavement section, but also by what he observes. A road with visible damage will be worse rated than a road with reduced visual damage.

Finally, the models developed on the present investigation could be used as an effective and objective instrument to assist the maintenance & rehabilitation decision making process; saving time and money on public investment, and thus achieve an increase in the welfare of the urban population of Colombia.
ACKNOWLEDGMENTS

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</table>

KEYWORDS:
Ground Penetrating Radar, Asphalt Pavement, Cavity, Nondestructive Test, National Highway

ABSTRACT:
Recently, the road-sinking phenomena collapsing of roads to the city are emerging as a social issue in Korea. These phenomena are not only causing damage to human lives and properties, but also an anxiety of the citizens. Furthermore, it is a problem that needs more fundamental solution to countermeasure. In order to prevent the road sinking, the Ministry of Land, Infrastructure and Transport advised the local governments to report the areas suspected of sinking. Korea Institute of Construction Technology inspected total of 19 reported areas on 10 points of the ground penetrating radars (GPR), and 2 sections were determined to have possibilities of sinking in the future.
This paper explains the principles and theories of inspections using GPR, and shows the process and results of field inspection. In addition, it suggests suitable frequencies of cavity inspection 1.5 meters under pavements, as well as verifying the experimental results by comparing them to the values obtained from experimental cavity test-bed. In the future, based on this study, a more accurate inspection technology is to be established through in-depth studies such as 3D interpretation, and obtaining more accurate dielectric constants.
A Preliminary Study on Cavity Inspection in Pavement Foundation Using Ground Penetrating Radar

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1. INTRODUCTION

Recently, as shown in Figure 1 the road sinking in Korea is causing frequent damages to human lives and properties, but also an anxiety of the citizens. A total of 3,328 locations have been found with existence of cavities in the past 5 years in Seoul, Korea. Since road sinking is causing anxiety and posing threat to the drivers and pedestrians, a systematic prevention and countermeasures against road sinking is urgent issue. Therefore, routine field inspections are needed to investigate the condition of pavement foundation, and appropriate repair work and reinforcement measures on locations with cavity should be taken immediately. Lately, GPR equipment is utilized to inspect the piers of the bridges, structures, tunnels, underground utilities, and pavement foundations (Andre Costa et al, 2010).

Figure 1  Road sinking case in Korea

Ground Penetrating Radar (GPR) is equipment that transmits the electromagnetic radar at the object, and detects the energy that is reflected on the boundary at which the material property changes. In addition, it has advantages in that it can inspect the condition of pavement foundation of a nondestructive and continuous manner. Normally, the frequency of GPR should be determined by the characteristics of medium and location and size of objects. Kim et al (2004) reported that antenna of 500MHz~1,600MHz is most appropriate at exploration depths within the range of 0~1.5m in pavement structure.

A GPR survey has been conducted on a total of 19 locations on 10 routes on national highways in Korea. A GPR equipment with 500MHz and 1,600MHz frequencies was used to investigate the possible existence of cavities on pavement foundation in these locations. GPR signals response data onto two frequencies have been compared and verified using GPR signal shape obtained from artificial cavity test bed.

2. THEORETICAL BACKGROUND

2.1 Applications of GPR

As shown in Table 1, the GPR is widely used in the areas including civil and architectural engineering, geology, transportation, archaeology, and environmental science.
Table 1 Applications of GPR

<table>
<thead>
<tr>
<th>Area</th>
<th>Application Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil/ Architectural Engineering</td>
<td><em>Obstruction detection</em>, inspection of steel reinforcement conditions, inspection of concrete thickness, verification of grouting effect, <em>cavity detection</em>, diagnosis of concrete and stone structures</td>
</tr>
<tr>
<td>Geology</td>
<td>Inspection of bed rock, inspection of strata, exploration of abandoned mines</td>
</tr>
<tr>
<td>Transportation</td>
<td>Inspection of pavement thickness, <em>inspection of foundation of tracks and roads</em>, inspection of runway conditions</td>
</tr>
<tr>
<td>Archaeology</td>
<td>Tumulus exploration, ancient ruins exploration, inspection of erosion in ancient buildings</td>
</tr>
<tr>
<td>Environmental Science</td>
<td>Exploration of underground contamination, exploration of underground storage tanks, detection of toxic waste, inspection of landfill condition, measuring the depth of river/lakes, detection of underground tunnels</td>
</tr>
</tbody>
</table>

2.2 Fundamentals of GPR Exploration

As shown in Figure 2, the GPR is an exploration method that utilizes the observational radar on for underground exploration; it is a method of physical exploration, in which the high frequency electromagnetic energy is emitted through the transmitting antenna, that is grounded, to the interior of the main medium, and a signal that is reflected on buried objects of the main medium is transformed into pulse radar at the receiving antenna, which is the imaged of the monitor for interpretation (Son et al, 2000).

Radar exploration investigates the location, depth, size, and shape of the anomalous objects underground through observing the radar cross-section. For example, it is frequently utilized for exploration of ① buried pipelines, ② buried objects such as waste, ③ cavities (especially those located under paved road, or at the back of the tunnels) · underground cavity in mines and basements, ④ buried ruins, ⑤ layer-fault-crevice (especially those containing water), ⑥ water table, aquifer, ⑦ subsurface, such as boundary of basement rocks and stratum, ⑧ sediment on river bed, lake bed (Hong et al, 2007).

![Figure 2 Schematics of GPR inspection](image)

2.3 Surface Dielectric Constant

In order to measure the dielectric constant of the surface layer of pavement structure, two experimental GPR data values are needed. The first are the GPR data obtained from pavement surfaces, and the second is the GPR data obtained from pavement surfaces with a metal plate. As shown in Equation (1), the dielectric constant of the surface layer of the pavement structure is calculated with the ratio of the GPR value reflected...
on the metal plate, and the GPR values reflected from the surface of the pavement structure (Lahouar et al., 2002). The GPR measurement of the metal plate is carried out at the same conditions as the main GPR measurement of the pavement structure.

\[
\varepsilon_r = \left( \frac{1+\frac{A_p}{A_1}}{1-\frac{A_p}{A_1}} \right) \tag{1}
\]

Here, \(\varepsilon_r\) signifies the dielectric constant of first a layer of pavement structure; \(A_p\), the GPR value reflected from the surface of pavement structure; and \(A_1\), the GPR value at the metal plate.

3. FIELD TEST

The field test was conducted at 19 locations on 10 routes in national highways. The test sites that showed possible road cavity according to the Ministry of Land, Infrastructure and Transport, and the sites near poor condition pipelines or culverts older than 20 years were selected as inspection sites. There are higher possibilities of cavity formation near the deteriorated pipelines and culverts due to high volume of soil erosion caused by the inflow of underground water or rainwater.

This study only mention the 2 sites that showed the possibilities of cavity formation of the future, out of 19 sites inspected with GPR. As shown in Figure 3(a), the field inspections were carried out with the restricted traffic, and one inspector carried out the inspection at a steady rate at the cavity suspected sites. There was a recent excavation repair work for the underground facilities near the site on Route 39, during which there were difficulties with the compaction and construction conditions, which is suspected of causing the formation of cavities. The site near the tunnel on Route 56 was inspected as shown in Figure 3(b). A displacement of the pavement was progressing at this site, and this site was found to have high a possibility of future road sinks due to loss of soil at the top of the road. The disturbance in flow of rain caused by the deterioration of the drainage system near the culvert located under the pavement is considered to have caused the soil loss.

![Figure 3 Field inspections of sites on national road suspected of cavities](image)

In order to verify the data obtained from the aforementioned field inspections, the data was compared with the data obtained from the experimental cavity test-bed designed by the Korea Institute of Construction Technology. The Testbed were designed with a cross section as shown in Figure 4(a), with a rebar, a steel plate, and Styrofoam cavity, which has a similar dielectric constant as air, and was inspected as shown in Figure 4(b).
4. TEST RESULTS

The data obtained from the field inspection were analyzed using the 2D analyzing a program from Company M, GroundVision Ver. 1.26.1 and PRLate Ver.0.3. Ten measuring lines 30cms apart from each other were investigated per site, and among those, the cross sections that showed the clearest form of cavities were selected as Figures 5 and 6. Two radar equipment of 500MHz and 1,600MHz were used, and the obtained data was compared with shown in Figure 5(a), and 5(b). As a result, the radar with 1,600MHz of frequency was determined to be appropriate for measurement of pavement thickness and asphalt mixture density, and the radar with 800MHz was determined to be appropriate for inspection of cavities under the pavement.

At cavities suspected a site on Route 39, a cavity with estimated 20~30cm diameter was located at 1~1.3m depth of surfaces of pavements. Similarly, as shown in Figure 6(a) at a site on Route 56, a cavity with estimated 20~30cm diameters was found 0.8~1.1m under the pavement.

In order to verify the formation of cavity, the GPR output was compared with the GPR output of the Styrofoam, which has a similar dielectric constant to air, in the Testbed designed by this institute. As shown in Figure 7(a), the signal form of the rebar showed a distinct parabola shape with a gradual slope, and the signal form of the steel plate showed a distinct parabola with a steep slope. In comparison, the experimental cavity showed a less distinct parabola with many lower slopes compared to those of rebar and a steel plate. According to the shape of signal responses of material mentioned above, there is some possibility of existence of either structure or cavity on Route 39 and high possibility of a cavity at the site on Route 56.

In the future, a more in-depth researches will be carried out by compiling multiples measuring lines of a 3D projection to allow for more accurate determination of the cavities, and by designing new testbed with cavities of different sizes to investigate the change in form of frequency according to change in size.
Figure 5(b) Analysis screen of cavity suspected site on Route 39 (1,600MHz)

Figure 6(a) Analysis screen of cavity suspected site on Route 39 (500MHz)

Figure 6(b) Analysis screen of cavity suspected site on Route 39 (1,600MHz)

Figure 7(a) Analysis screen of experimental Testbed (500MHz)
5. CONCLUSIONS

To investigate the possibility of road sinking frequently occurred in these days, the field survey has been conducted using the GPR on 19 locations of national highways in Korea. Testing data were analyzed to identify the shape of GPR signal for the cavity in the pavement foundation. In addition, the analyzed data were verified through comparison of the data obtained using the experimental cavity testbed designed and built by the KICT. The followings are the conclusions of this study:

- Out of 19 sites on 10 routes, the GPR output data onto sites suspected of cavities near Route 39 and a tunnel on Route 56 were studied.
- GPR with frequencies 500MHz and 1,600MHz was used for inspection, and frequency of 500MHz was determined to be appropriate for identifying the cavities located at the 1~1.5m underneath the pavement.
- After reviewing the B-scan data, cavity of 20~30cm size is considered to exist at 0.8~1.3m under the pavement, and more accurate result will be obtained by estimating the dielectric constant of the inspection site.
- By compiling the 2D cross sections in the 3D projection program made by Company M, the size of the cavity will be more accurately estimated.
- In the future, a more accurate cavity exploration will be aimed to comparing and contrasting the waveform of the frequencies of the medium.

ACKNOWLEDGEMENTS

This research was supported by a grant from a government funding the project (National Highway Pavement Management System).

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Jaakko Rahja

MANAGEMENT OF LOW-VOLUME, PRIVATE ROADS

IN FINLAND

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ABSTRACT

In Finland road network is totally 450 000 km, of which the length of private roads is 360 000 km. These private, co-operative roads are really low-volume but still they play an extremely important role in the whole road network.

Some 10 per cent of the population lives along these roads, some 100 000 km are with permanent settlement. Major part of summer cottages and other recreational buildings are located in the area of influence of these roads. And major part of timber haulage and agriculture uses private roads.

The rules for private road management come from the special Act (Law) on Private Roads. The management system in Finland is quite unique, for example there is a special Act on private roads (co-operative roads) only in very few countries.

According the Law the property owners and other regular road users – who have a right to use the road - have the management responsibility of these roads. The form of management is a cooperative. Every property owner - benefiting from a road - has to participate in management and cost covering. In annual meetings the cooperative members select a trustee or triumvirate of the cooperative and also decide annual budget, the level of maintenance, the need and financing of road reconstruction, possible bank loans and in fact all the most important issues. The trustee or triumvirate manages the cooperative between annual meetings.

These low-volume roads are located mainly in rural areas. There some problems have been raised up on management of these roads, like
- the number of permanent residents in rural areas is decreasing and persons are ageing
- it is more difficult to find voluntary successors, responsibility and numerous tasks involved are in conflict with the low remuneration for these tasks
- know-how of road management, maintenance and repair has decreased
- challenge to find small entrepreneurs to take care of practical works like snow ploughing, sand spreading or other tasks related to road maintenance. Contract, whose length is only a couple of kilometres is not interesting (not enough for sufficient equipment investments).

As one solution for the above mentioned challenges and to give help to co-operatives in their private road management the Finnish Road Association
- has trained some 250 persons for a secondary occupation “Private Road Manager”
Jaakko Rahja

- has published three guidance books (road maintenance, management ja repair)
- operates the Private Road Call –service (Help Call) to those who have responsibility for private roads
- organises Private Road Days all over the country, every 2. year, including education in management and maintenance and repair

Finnish private road management system, PRMs and other help tools for road co-operatives are globally unique; scarcely there are no other countries which have the same systems except Sweden.

LOW-VOLUME ROADS IN ROAD NETWORK

In most countries the National Road Administrations have responsibility of highways and main public roads while urban roads and streets are generally managed by City Councils or municipal administrations. But there are various practises concerning the management of low-volume, very smallest roads like rural access, agricultural roads etc. (usually 100 vehicles per day or even less).

![Schematic Diagram of Rural Low-Volume Roads in Finland](image)

**Figure 1** Road network includes state roads but also low-volume private roads, co-operative roads. In Finland the whole road network is 450 000 km, of which the length of private roads is 360 000 km.
PRIVATE ROAD SYSTEM

In Finland there is a special and widely praised system how these smallest, low-volume “Private roads” or “Co-operative roads” are managed. The rules for management of these roads come from the special Act (Law) on Private Roads.

The usufructuary right to use a private road is established in a private road survey. Property owners who use the road are normally road partners.

Road partners are collectively responsible for road management. They may operate either “unorganized” or establish a private road cooperative. If unorganized, all decisions have to be reached by mutual unanimous agreements. A private road cooperative is an “organized” way to manage a road.

The road cooperative elects a body to organize the affairs of the road. The elected body may either be a board of three persons or only one trustee. The private road cooperative makes decisions on matters related to road management in regular meetings. Decisions in the meetings are made by majority vote and they are binding on all partners.

The road cooperative is established either in a private road survey or a survey carried out by the municipal road council.

Road partners are responsible for the construction and maintenance of private roads at their own expense. To cover the costs partners have to pay road charges. These charges are apportioned between road partners based on the traffic required by the properties.

The Private Road Act governs many activities of private road cooperatives. Rules are laid down to establish the proper procedures, for example, to summon meetings, prepare the agenda and maintain minutes of the meeting, accept new members, make decisions on road units and road charges etc.

However, road cooperatives may exercise considerable discretion concerning the standard and maintenance of the road. The road cooperatives also decide on the financing and timing of road management operations.

The private road board is responsible for the fulfillment of the road cooperative activities and for the legality thereof.

It is advisable that road cooperatives plan their activities according to the accounting period. The statutory duties of the private road board include, amongst others, accounting, the preparation of a schedule of proposed road charges and the summoning of meetings. Important issues which are to be included in the agenda of the general meeting include the presentation of an annual report and approval of financial statement, the proposed action plan and budget for the following year.

Even though road members are themselves primarily responsible for financing road maintenance, the private roads which are important to traffic and local residents are entitled to subsidies from state and municipality. Municipalities may provide subsidies at their own discretion, mainly they assist in general annual maintenance. State subsidies are intended basically for reconstruction and improvement projects, such as the improvement of load bearing capacity and drainage systems and the renewal of bridges.

Surveys carried out by the road councils of municipalities deal with questions concerning existing private roads. They also handle complaints about the decisions of road cooperatives. It is possible to lodge an appeal against the decision made by a municipal road council with the Land Court.
Many Finns have to manage and maintain, at their own expense, private roads which provide access to homes, summer cottages, parcels of forest or arable land.

PRIVATE ROAD MANAGERS

The Finnish Road Association has taken a quite wide responsibility to develop modernize the private road system in many ways. Association has trained special “Private Road Managers” (PRM) to take in charge of management and administration of one or more road cooperative.

The most common case nowadays is that a PRM operates as a trustee – like a managing director - or adviser to the road cooperative.

Private Road Manager is a person who - slightly professionally - takes care of the administrative tasks, including cooperative’s economy, and maintenance. Skilful PRM is also a valuable asset for in the management of a major reconstruction project. Planning, applications for public assistance, organising competition among contractors and supervision of the project are demanding tasks.

PRM has an ability to take care of several separate private roads in the village. Then he is able to collect bigger maintenance contracts. Experiences show that cost savings can be considerable, 5…25 %. Contractors are interested if ploughing or ditch maintenance projects are bigger. New situation creates competition and also it is easier to make longer lasting contracts. The contractor has courage to invest on new equipment.

Until summer 2015 some 250 PRMs have been trained all over the country. On an average, they are now responsible for 20 road cooperatives but some of them even as much as 50.

Experiences have been very positive both as far as PRMs and road cooperatives are concerned.

PRM training is organised by Road Association and partly financed by the Transport Agency and Ministry of Transport and Communications.

During the training PRM gets a knowledge of legislation, management and different kind of technical issues. Compact training package consists of 3 sections lasting 3 days, totally 9 days. Also some homework is included in advance and before sections. The training ends up with an examination. Certificates are submitted to participants who pass the test.
FIGURE 3 Road maintenance and repair may be expensive and demanding for non-professional estate owners. A skilful Private Road Manager is able to help by managing road cooperative, planning and organising competitions and supervising maintenance and reconstruction works.

OTHER HELP-TOOLS FOR PRIVATE ROAD CO-OPERATIVES

Road Association operates the Private Road Call –service. Everybody who has questions dealing with private roads (management, maintenance, repair, Act, construction …) is able to call to the number 0200 345 20. There are three skilful PRMs at the time answering to these questions, on every working day at 9-18. A call costs EUR 1/minute.

There are also new guidelines for private road co-operatives, published by Road Association:

- Private road co-operative management (published in 2013, 164 pages)
- Low-volume road maintenance (2012, 108 pages)
- Low-volume road repair (2010, 140 pages)

Every second year the Road Association organises Private Road Day –events for those who are responsible for their private roads. All day event includes information about Act, road management, maintenance, repair, road using etc.

FIGURE 4 Private Road Day –events are for those who are responsible for their private roads.

CONCLUSIONS

Low-volume private roads play a very important role in the road network, especially in countries like Finland.

The asset value of private roads in Finland is estimated to be EUR 3 500 million and replacement value EUR 6 500 million, bridges (some 20 000) excluded. Hence they constitute a valuable national property.
The assistance from government and local municipality has decreased. Private road cooperatives have not had enough financing to implement most expensive and most important tasks like maintenance of ditches and culverts, gravelling and grading. As the result there is a risk that condition of private roads weakens.

It has been noticed that private roads should manage more professional. They should and can be collected to bigger units administratively in some ways. Private Road Manager is one good help for cooperatives and for collecting bigger contracts. It is also possible to develop private road network either by joining several road cooperatives or by establishing totally new type of road cooperative units. And in these cases the Private Road Managers could be the “managing directors” of these bigger units. Management of private roads could then be also more professional when a skilful PRM is taking care of this bigger road unit and its roads.

In any case, it is clear that cooperation between road cooperatives must be increased. Administrative changes are not needed in every case.

According to Finnish experience it is clear that increasing of road know-how is maybe the most important. Those who have responsibility of these roads - the property owners and other regular road users – should know how and when to do right things and use right materials, machines and equipment.

This Finnish private road system and help tools have proved to be quite effective management model for low-volume roads. It could be valuable also in other countries where property owners and other regular road users are responsible for their road keeping.
### ABSTRACT:

Billions of dollars are annually invested by road agencies in bridge maintenance, rehabilitation, and reconstruction (MR&R) in the United States and around the world. In the ever-present context of limited budgets, it is critical to determine the most cost-effective allocation of resources across the different Structures of a network. Bridge Management Systems (BMS) have been developed to maximize the return on investments of public (and/or private) funds allocated to these structures.

This paper describes the development and validation of three different bridge re-source allocation optimization approaches using integer programming. The first approach follows the assumption that an MR&R project always includes all actions that are pertinent for all bridge elements at that point. The second approach follows same assumption, but in addition also considers total bridge replacement as an alternative project. The third approach allows an MR&R project to be composed of any combination of independent element-specific actions. All the three approaches are formulated and implemented for single-year and multi-year problems. The developed methods were applied to the 2013 bridge dataset of the state of North Carolina including approximately 13,500 bridges. The study results show that all methods can effectively solve industrial-size problems and significantly improve the current state of practice; while neither of them is always superior to the other.
Using a holistic approach to infrastructure maintenance

INTRODUCTION

Bridge management in the US has made major progress in the past 40 years, with significant accomplishments at the Federal and State levels. In the 1960s and 1970s, maintenance and rehabilitation activities were mostly performed on an “as needed” basis [1]. This practice was revisited in the late 1960s after a series of bridge failures attracted the public’s attention. This led to the implementation of mandatory inspection programs (imposed by the Federal government) and the systematic adoption of computerized BMSs in most road agencies [2]. More recently, the limited or reduced budgets emphasized the need for these systems in order to yield more balanced, rational, defensible, and cost effective decisions.

Modern BMSs are expected to include some optimization mechanism for long term MR&R work plan composition. Bridges are different from other transportation assets in their complexity. Bridges consist of multiple elements and the performance of each bridge is a function of its elements’ performance. In general, MR&R actions are applied to individual yet dependent elements, while the overall objectives/constraints of BMS optimization are defined on the bridge (not element) level [3]. This contributes to the complexity of the problem.

Treatment and project selection is a major component of most BMSs [4]. While there is an agreement in the literature on the benefits of using optimization for treatment selection, little work has been done to quantify the impact of different optimization approaches in industrial-sized asset management networks.

This paper describes the development and validation of three different bridge resource allocation optimization methods using Special Order Sets Integer Programming. The first approach follows the assumption that an MR&R project always includes all actions that are pertinent for all bridge elements at that point. The second approach follows the same assumption, but in addition also considers a Total Bridge Replacement (TBR) as an alternative project. The third approach allows an MR&R project to be composed of any combination of independent element-specific actions. All the three approaches are formulated and implemented for single-year and multi-year problems.

The developed methods were applied to the 2013 bridge dataset of the state of North Carolina, which consisted of approximately 13,500 bridges. The study results show that all methods can effectively solve industrial-size problems and significantly improve the current state of practice - while neither of them is always superior to the other.

The findings of this study can be used to improve the economics of bridge management agencies by providing guidelines for choosing more efficient optimization formulation. Also, this study can help agencies to set more informed goals for the performance of their network. This study is performed on a bridge network. However, due to the high level of similarity in management optimization framework, the results can be generalized to other transportation assets (e.g. pavement, maintenance and fleet).

BRIDGE NETWORK PROGRAMMING

AASHTO defines asset management programming goal as “how to efficiently allocate resources so that network conditions are maximized (the objective function) and costs are minimized (the constraints)” [5]. Ranking and prioritizing procedures have been widely used by several DOTs to allocate resources to bridge projects [6]. However several drawbacks have been mentioned in the literature including [7]: Results of ranking methods are not optimized. In fact, the results of ranking can even be worse than random selection of projects. Also, ranking results are based on overall condition of bridge and do not accurately reflect bridge elements repair needs. The results of ranking analysis are not also sensitive to certain important factors such as average daily traffic.

Incremental Benefit Cost Ratio (IBCR) is another popular method of resource allocation. This method was applied by McFarland in 1979 [8] to public road investment and implemented for BMS in 1988 [9]. In this method, the IBCR values for all assets are combined into a single list and sorted in decreasing order [9]. Major drawback of this method is the inability to handle analysis constraints (e.g. specifying the budget by work type) when performing network programming simulation [10, 11].

Heuristic optimization methods have also been devised to solve bridge network programming problems [12, 13, and 14]. Major benefits of using these methods are the ability to model the trade-offs between different project timing and the impacts on bridge performance, and ability to handle numerous and complex dependent constraints [5, 15].

However, the size of the optimization problem grows exponentially with the size of decision variables and this can lead to a serious issue for industrial-sized networks; As an example North Carolina Department of Transportation (NCDOT) network has about 13,500 bridges (structures with a span of 20ft or 6m), each bridge is assumed to have three elements;
Each element can have 23 treatment types on average, and the planning period can be over 25 years. The analysis needs to consider dependencies between bridge elements treatment (e.g. if substructure gets replaced, deck also needs to get replaced) and also needs to handle several constraints on average network condition, percent-age of network above/below a condition threshold etc. [16].

Thompson et al. [3] reported that running optimization analysis takes one minute for 1,000 bridges, 2.5 hours for 12,000 bridges, and 1.7 days for 50,000 bridges. They also reported that “The largest network we are dealing with is of 50,000 bridges. Each bridge could have as many as 5 possible interventions including the do-nothing alternative. This is a huge integer programming problem, so approximate heuristic methods are very appropriate. Therefore, they suggested using Incremental Utility Cost (IUC) method in which investment alternatives are arranged in decreasing order of reward to cost ratios. The algorithm simply scans down the list to fill the select project list (i.e. knapsack).

In separate studies [12, 13, and 14] Scheinberg et al. invented an integer programming optimization formulation and routine and reported its effective applications on industrial-sized infrastructure management problems. The focus of this paper is introduction and validation of three variations of this method.

REDUCED BRIDGE MAINTENANCE OPTIMIZATION MODELS

Bridge Maintenance (BM) problem is a multi-year optimization problem. Considering true multi-year optimization models are not possible or practical due to the size. In this paper two size reduction approaches used - dividing single multi-year problem into several single-year models and using of decision mechanism, in particular, decision trees.

Three single-year approaches to the reduced formulation of the main BM problem and general multi-year formulation are presented.

The first approach follows the assumption that an M&R project always includes all actions that are pertinent for all bridge elements. The second approach follows same assumption, but in addition also considers a “Total Bridge Replacement” (TBR) as an alternative project. The third approach allows an M&R project to be composed of any combination of element specific actions, including TBR. The last approach considers all time periods at once but considers only a limited number of available strategies.

Every model can have many different types of constraints. This paper focuses on how bridge objects can be modeled in an Integer Program (IP) and, thus, considers only two types of constraints to keep formulations simple. The two types of constraints are total annual budget constraint and Above Threshold constraint for performance index that keeps a percentage of all bridges above a certain performance threshold.

Single -Year Model

The first model finds the optimal set of recommended projects to include into M&R work plan for a given year. Decision trees mechanism recommends only one project per bridge. If there are T time periods then T such models are solved where output from previous year is an input to the next one. The model maximizes weighted total improvements.

Single-Year Model with Alternatives

The difference between this model and Single-Year Model is that it considers several projects per bridge. Thus this formulation can utilize top-bottom (when bridge element treatments assigned based on overall bridge performance) and bottom-top (when bridge element treatments assigned using bridge element condition) approaches to designing projects. For example, one can consider only two projects per bridge “element” project and “bridge” project. The “element” project is designed using bridge element decision trees. The “bridge” project is designed using bridge decision tree that recommends treatments based on overall bridge performance. In other words, the model maximizes weighted total improvements.

Single-Year Model by Elements

Previous two models are operating on projects that cover the entire bridge. This means that models cannot choose to fix only part of a bridge. All recommended treatments per bridge must be executed. Single-Year Model by Elements allows picking a subset of recommended treatments. Only one alternative per element is considered. However, since entire bridge is part of the element set top-bottom and bottom-top approach for designing projects can still be used. As before the model maximizes weighted total improvements. First constraint restricts total spending. Since total bridge improvement is now a function of x the Above Threshold constraint was adjusted accordingly.

Strategy Multi-Year Model

So far, single-year models formulations are discussed. The final model is a multi-year model that considers a limited number of bridge strategies and picks the best strategy for each bridge. A Bridge strategy is an object that stores all information about a bridge (and its elements) over the time period considered. This includes specific treatments and treatment schedule. A set of strategies per bridge is assumed to be given. How to create such a set to make sure
optimization achieves decent results is a subject of another paper. The main advantage of this approach over others is that this model considers the entire time horizon at once. Hence, the model is minimizing/maximizing the overall performance of weighted bridge inventory while satisfying annual budget and Above Threshold constraints while choosing exactly one strategy for each bridge. For additional details on models with similar formulation see [12,13, and 14].

**CASE STUDY APPLICATION**

This section discusses the parameters and assumptions required for optimizing project selection process based on NCDOT’s current practice. NCDOT has been used in this study since it has a long history of prioritizing funding to maximize operational and maintenance costs. NCDOT planning policy is featured as a model for other DOTs by Federal Highway Administration (FHWA) [16]. NCDOT currently uses the AgileAssets Analyst™ for his bridge management system (BMS). The dataset, performance models, decision trees, and treatments presented below already exist and have been leveraged in this study.

**Network and Dataset**

The NCDOT currently maintains about 13,500 bridges across North Carolina, ranking as 13th in the nation for the highest number of state-maintained bridges [17] and 14th for bridge surface area with more than 28 million square feet of bridge deck to maintain [18].

The dataset used in this study contain inventory data (e.g. bridge structure, geometric data, location, and owner), traffic data (e.g. Average Annual Daily Traffic (AADT), speed limit and functional classification), MR&R history, and bridge performance data (i.e. inspection and testing data) for NCDOT network.

Each bridge in North Carolina is inspected at least every two years in accordance with the National Bridge Inspection Standards (NBIS) [17]. According to NBIS, condition data are collected and stored on a 0-9 scale [19] (9 for a “Superior to desirable” bridge and 0 for a closed bridge) on each bridge element. The elements are defined as [20]:

- **Deck**: The portion of the bridge that directly carries traffic
- **Superstructure**: The portion of the bridge that supports the deck and connects one sub-structure element to another
- **Substructure**: The portion of the bridge that supports the superstructure and distributes all bridge loads to below-ground bridge footings.

Individual elements scores are then used to calculate an aggregate bridge condition performance index called Bridge Health Index (BHI). The BHI is a straight average of the 3 individual element scores transformed into a 0-100 scale (100 is considered perfect – Deck, Superstructure, and Substructure would have an individual index of 9).

**Bridge Performance Modeling**

NCDOT’s bridge performance models were used to predict performance of bridges in this study. Bridges with similar material type (e.g. wood and timber, reinforced or pre-stressed concrete and steel) of deck, super-structure and sub-structure are assigned similar performance models. These performance models are piecewise linear and are used to predict the BHI of the bridge as a function of its age.

**MR&R Assignment**

NCDOT uses decision trees to assign the “right” treatment for each bridge element for each year of analysis. The most important factors considered in decision trees are material type (e.g. wood and timber, reinforced or pre-stressed concrete and steel) and condition rating of each individual bridge element.

**Common Objectives and Constraints**

The NCDOT applies its BMS’s performance prediction capability to produce long-term scenarios of bridge needs that allow it to produce a variety of analyses scenarios and results [21]. Most common objectives and constraints of these analyses are:

- **Objective**: NCDOT defined Principal goal of using state funds as maximizing average network’s BHI. NCDOT currently provides a Bridge Health Index of 64.2 percent for its entire bridge system [17]. NCDOT’s target is to have at least 65% of network bridges in good condition. In 2013, 64.9% were in good or better condition [18].
- **Constraints**: Total available budget for bridge MR&R is limited. In 2012 and 2013, about $450 million in state funds have been invested to replace, preserve or repair bridges. Additionally, proposed state budgets include about $300 million to continue the program in 2014 and 2015 [22].
According to state and federal regulations (e.g. STIP and TIP), certain portion of total bridge MR&R budget needs to be devoted to MR&R actions in defined categories (e.g. replacement, maintenance, rehabilitation and preservation). Currently, NCDOT allocates approximately 5% of the state budget to bridge maintenance and 1% to Preservation [16].

MR&R Budget districts are limited to a certain portion of state’s total budget based on unit’s needs and various other considerations.

**Optimization Routine**

NCDOT performs bridge management using AgileAssets Bridge Analyst™, a commercial asset management software package. NCDOT’s simplified bridge management optimization analysis process is depicted in the following figure.

![AgileAssets Bridge Network Programming Process](image)

**Figure 1: AgileAssets Bridge Network Programming Process**

This process can be summarized in the following steps:

1. For each element on a bridge, the system will evaluate the condition of this element in the year of the analysis (1st year of the analysis is the last known condition already deteriorated by 1 year)

2. Each element is run through its defined decision tree. A treatment (including “Do Nothing”) is recommended by the decision tree, the element is put aside, and the system will move to the next “element” and repeat the same logic.

3. Once all the elements on a structure have been “scanned” then all the treatments are applied and their “improvements” are applied.

4. All the treatments are combined into a project for the bridge and the benefits are also aggregated, along with the costs. This assembled project for this structure becomes a candidate for the mixed integer optimization analysis.

5. In case the sum of the recommended treatments costs is superior to the Bridge Replacement Cost x Cost Replacement Threshold (default to 80%), then the system will overwrite the individual element treatments with the Bridge Replacement treatment.

6. This process is repeated for each structure in the scope of the analysis.

7. Once the preprocessing is completed, the candidate projects are pushed into the mixed integer optimization solver.

8. This solver operates on a set of decision variables that consists of the “bridge project candidates” meaning that for each participating bridge analysis considers only two possibilities: do the project that is, realize all the treatments included in this project, or “do nothing”

9. The solver solution will consist of bridge projects. The solver finds the optimum solution according to the selected Objective and defined Constraints.
NUMERICAL RESULTS
In this section all four formulations are used to design 10-year M&R work plan for the case study network. With this setup every model is using the same input. The goal is to find a 10-year work plan that minimizes total cost and, first, keeps average bridge performance rating above 74 in every year and second makes sure that at least 70% of bridges have a rating above 65. The purpose of this example is to demonstrate that, depending on formulation, differences in work plan can be quite dramatic and to show how important it is to have the right data inputs.

Figure 2: Total 10-year spending

Figure 2 shows the total cost of the obtained work plans for each model formulation. The results suggest that “By Elements” formulation performed the best. It found a work plan that would spend about 687 million dollars over 10 years. “Multi-Year” model came in second with $847 million budget. “Single-Year” model performed the worst with total budget of just over 1 billion dollars. The budget distribution for each formulation over time is presented in Figure 3.

The “Single-Year with Alternatives” model performed virtually the same as the “Single-Year” model, as shown on Figure 3, but was able to benefit from the availability of more alternatives in year 6. Where the “Single-Year” formulation is using reconstruction projects, the “Single-Year with Alternatives” formulation utilizes the less expensive Major Rehabilitation option, thus, reducing the cost. Why didn’t the “Single-Year” formulation use the Major Rehabilitation treatments? The projects designed for “Single-Year” use both “element” and “bridge” decision trees. Out of the two project types, the one with the heaviest treatments wins and becomes an input to the “Single-Year” model. In this case, the Reconstruction option won over the Major Rehabilitation option, so the “Single-Year” model did not have any Major Rehabilitation projects to choose during optimization analysis for some bridges. However, the “Single-Year with Alternatives” model uses both projects as an input and picks the best out of the two during optimization.
A detailed work plan analysis reveals why the “By Element” method came in first place. Table 1 shows that the “By Element” analysis focused mostly on fixing Decks and Substructures as these are the cheapest elements to fix, largely ignoring the Superstructures. The other formulations had a more even distribution of repaired elements. In short, the “By Elements” analysis figured out that fixing decks is order of magnitude cheaper than fixing the other elements. This can be explained by the fact the deck elements have the same weight as the superstructure and substructure elements in the bridge performance rating, so the model focused on decks, sometimes fixing the second cheapest element - substructure when no "bad" decks were available. Does this represent a viable and practical solution? Most engineers would not approve of such plan. To fix this formulation’s caveat so that it would produce a usable work plan, substructure and superstructure elements should have higher weight than the deck elements in the combined bridge rating number.

What about the “Multi-Year formulation”? A detailed work plan analysis reveals that it spent more on fixing heavy bridge elements such as Superstructure and Substructure. Also, as shown on Figure 3, the “Multi-Year” formulation demonstrates the ability to plan ahead instead of reacting to the current situation. Indeed, as one can see, the “Multi-Year” model is the only model that started with heavy spending, enjoying healthy performance later. In contrast, the “Single-Year” formulation did not spend as much in the beginning which led to a crisis of options in Year 6. In Year 6, the only solution that the “Single-Year” model could find to satisfy the constraints was to do several bridge reconstructions - projects that everyone tries to avoid because of their high cost. The other “Single-Year” formulations also had problems in year 6. This can be explained by the fact that “single-year” models fail to account for benefits of treatments done in the future.

Which of the models could be recommended for practical use based on this study? For initial exploratory analysis, “Single-Year with Alternatives” or “By Elements” (given objective was modified as discussed above) formulation
seems to be a good fit. For the final analysis, once it is clear what the objective, performance targets, and constraints should be based on initial analysis, then the multi-year analysis should be used.

CONCLUSION
This paper described the development and validation of three different bridge resource allocation optimization approaches using integer programming. All the three approaches were formulated and implemented for single-year and multi-year problems. The formulations were applied to a bridge network of approximately 13,500 bridges. The study shows that each method has certain advantages and can achieve significant savings for the agency using these state-of-the-art tools. It is important to note that a calibration effort is necessary for each element weight in order to achieve reasonable output. This study shows that the formulations are important when optimizing a work plan. All the models presented in this paper are available in the Agile Assets Bridge Analyst™ as a commercial-of-the-shelf bridge management system.

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REFERENCES
1. ABSTRACT

With more than 5 million kilometers, European roads constitute one of the major community assets. We may believe that the condition of the road network is satisfactory. However what looks acceptable on the surface can be hiding significant problems below.

In EU Member States where surveys have been carried out there are indications that the backlog of outstanding road maintenance has caused irreversible deterioration of the road network. The shortfall in investment in maintenance generates higher risks of accidents, problems of congestion, increased noise and a reduced service to society;

The problem is that roads are not seen as a financial asset for society and the economy, largely due to the lack of awareness of their value. The consequence of not fully valuing these assets is similar to increasing our debt.

Many studies suggest that the only way to manage the European road asset so that they meet both needs and aspiration is to carry out regular surveys and undertake regular planned maintenance. Road Asset Management can help to achieve sustainable and effective management of a safe and efficient road network.

In the framework of its activities, the ERF has started a Working Group on Road Asset Management. This WG has carried out an extensive survey across Europe for the estimation of the value of the road asset. The working process of this WG will be presented, as well as the first results.

A second stage of the activity of the WG on RAM has been the publication of a ‘Manifesto for long-term, effective management of a safe and efficient European road Network – Keeping Europe Moving’. This Manifesto was mainly addressed to political representatives, decision makers and road authorities at all levels (European, national and local), in order to raise awareness on the essential value of the road as an asset and the necessity to maintain and preserve it.

The following step consisted in the publication of an ERF comprehensive Position Paper on Road Asset Management, whose content will also be described in the presentation. The following stages are focusing on communication. The outcomes of this work have to be released to different target audiences, at national and international levels. Different communication tools can be used for such a purpose. The presentation will detail some of the channels used for raising awareness on the RAM topic.

The achievements of the ERF WG on RAM (focused on the EU) can also constitute a useful tool for the estimation of the value of the Turkish road network and its necessities of preservation and efficient maintenance and upgrade.

2. KEYWORDS

Road Asset Management – Infrastructure preservation
Christophe Nicodème

INTRODUCTION

Road infrastructure is the backbone of the European economy and provides social equity, creating a source of unprecedented socio-economic wealth for Europe’s citizens. It is an essential part of the global transport and mobility framework, providing accessibility to services, trade, products and persons across Europe.

Currently, in the European Union (EU), the percentage of inland transport of goods by road represents 72.7% and the part of inland passenger road transport represents 83.5%.

In the White Paper for Transport published in March 2011, (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:EN:PDF), the European Commission (EC) addresses the challenges and objectives for the preparation of the European Transport Area for the future. This document considers transport as fundamental for economy and society. It clearly states that mobility is vital for the internal market and for the quality of life of citizens as they enjoy their freedom to travel. It also underlines that transport enables economic growth and job creation and is essential for the free movement of persons and goods, as well as for the economic, social and territorial cohesion.

According to the estimations of the European Union (EU), the growth in traffic between Member States is expected to double by 2030. The investment required to complete and modernise a well-performing trans-European transport network is substantial. In the same White Paper, the cost of the EU infrastructure development to match the demand of transport has been estimated at over 1.5 trillion € for the period 2010-2030.

The table below indicates the trends and outlooks in passenger transport demand for the different modes of transport in EU-25.

6.10 Trends and outlooks in passenger transport demand for the different modes of transport in EU-25 - 1990-2030 (Gkm)

Source: EEA

The following table shows the evolution of the Trans European Network of Transport (TEN-T) roads in length and type by 2020.
With such a forecast of transport demand, it is essential to build, upgrade, preserve and maintain a high-quality road network. This is the only way to keep on providing the citizens with the level of service that they are entitled to expect from roads, and to offer them high-quality and efficient road network, which is able to cope with the future challenges in terms of accessibility, mobility, safety, delivery of services and goods and sustainability.

With a total of some 5 million kilometers, the EU road network constitutes one of Europe’s largest community assets. However, chronic underfunding and lack of maintenance risk jeopardizing in a short time this huge asset, which has been built over the past 50 years at great expense and effort. Roads, like buildings, need to be maintained and have their own life cycle, which can be prolonged efficiently if the timely corrective action is taken in an appropriate way.

In all European countries, the current economic situation, the financial uncertainties and the budgetary constraints have considerably reduced the availability of funds for all purposes. However the underinvestment in road infrastructure, particularly during the last 10 years, has led to a critical point in time, where the continuation of the status quo may entail a situation where our network is damaged beyond normal maintenance requirements and necessary repairs would generate huge costs and could lead to a loss of value of the road asset.

The following table displays the evolution of the road maintenance share of total road expenditure in various areas of the world, and we can see that the trend is going down in Europe, particularly from 2006.
Another evidence of the continuous decrease of investment into the road infrastructure is displayed on the following table.


According to a report published in 2012 by Pro-Mobilität in Germany, the net asset value of regional, rural and urban roads in Germany has constantly decreased since 2003 (see next table).

![Net Asset (value of time) of regional, rural and urban roads](http://www.erf.be/images/stories/RRS_Policy_Statement_final_23_March_light.pdf)

Considering this situation, on request of some of its Members, the European Union Road Federation (ERF) has decided to launch a dedicated Working Group (WG) on Road Asset Management (RAM), in order to analyse the issue, propose solutions and increase awareness of the major stakeholders and decision makers at different levels: local, national and European.
4. THE ERF WG ON RAM

The ERF is a European non-profit organization, based in Brussels, which coordinates the views of Europe’s road infrastructure sector and acts as a platform of dialogue and research on road mobility issues. It defends the interests of the European road infrastructure community towards the EU institutions and other stakeholders, and represents a cross-section of industry partners, national roads’ and road users’ associations active in the construction, equipment, maintenance and operation of Europe’s road network. It also initiates and supports studies and publications aimed at increasing awareness on the importance of roads for all citizens, and it contributes to European research initiatives with the view of enhancing the overall efficiency and safety of the road transport system.

4.1 The rationale and first steps

In 2011, the ERF started a Working Group on RAM, gathering experts from different countries in the EU, in order to address the issue of RAM. The initial step was to establish a mission statement and a strategy for the WG. It clearly appeared that the major priority was to estimate the value of the road infrastructure asset in Europe. For this purpose, it was decided to gather data on the road network length in the EU countries (and some neighbouring countries as well). Different types of roads were listed:

- motorways
- national roads
- regional roads
- rural roads
- urban roads

The following step consisted in determining an average value per km for each type of road. Some discussions took place in the group, in order to determine which value should be chosen. There are, indeed, different approaches to determine the value of an asset and some accounting methods used in budget calculations do also take into account a value of depreciation. Finally, the decision was made to ask for the reconstruction value (that would be the average current cost to build a km of this type of road). The final calculation would then allow having an estimation of the value of the road infrastructure in the specific country.

Other information that we were looking for was the current annual expenditure for road maintenance in each country considered, in order to compare the level of maintenance investment compared to the value of the network.

We therefore established a questionnaire, to be sent to different countries (road authorities) in the format displayed hereunder.

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>Road Network (km)</th>
<th>Average construction cost per km (in M €)</th>
<th>Estimated value (in M €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>National Roads</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regional Roads</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rural Roads</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban Roads</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL KM</td>
<td></td>
<td>TOTAL VALUE</td>
<td></td>
</tr>
<tr>
<td>Annual Expenditure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Value Loss</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Concerning the number of countries involved in our research, we decided to limit this enquiry to a certain number of EU and neighbouring countries, according to a series of criteria:
Christophe Nicodème

- some major EU countries had to be in the list (e.g.; Germany, France, UK, Spain, Poland, Italy)
- some other countries were selected because some members participating to the WG would allow to gather information more easily (e.g. Belgium, Denmark, Finland, Norway, Croatia)
- on the base of the information received, by establishing an average reconstruction value for each type of road in Europe, and multiplying it by the respective number of km – this data is easily available – we could then establish an estimate of the value of the road infrastructure in Europe.
- We knew from past experience that some countries do not provide such information and we did not consider them.

4.2 The following steps and strategy
Once the figures gathered and the estimation of the value of the road network in Europe established, the following steps would have been to inform the major stakeholders (politicians and policy-makers, decision-makers and road authorities) of the importance of the road infrastructure asset and of the necessity to make cost-effective decisions for the maintenance and the preservation of the road asset value. The limitation of budgets available and the economic crisis require indeed to:
- carry out a global analysis of the condition of the road infrastructure
- identify priorities
- make necessary decisions for prioritizing funding
- find where the best return on investment can be found
- preserve and increase the asset value of the road infrastructure

The following objective of the RAM WG was the publication of a Manifesto aimed at raising the awareness of policy makers on the issue of the RAM.

4.3 The results of the data collection
As indicated, from past experience in data collection, we knew that this process would be long and time-consuming. What we could not imagine was how difficult it would be to collect valuable information, in many aspects.

One of the main results of this investigation was that many countries don’t use a common definition of the types of roads. For example, some countries include urban roads in the rural roads category (Croatia, Norway). The following table displays the information received from Croatia.

<table>
<thead>
<tr>
<th>Road Network (km)</th>
<th>Average construction cost per km (in M €)</th>
<th>Estimated value (in M €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways</td>
<td>8.5 M €</td>
<td>10.625 M €</td>
</tr>
<tr>
<td>National Roads</td>
<td>1.42 M €</td>
<td>9.670 M €</td>
</tr>
<tr>
<td>Regional Roads</td>
<td>1.1 M €</td>
<td>11.902 M €</td>
</tr>
<tr>
<td>Rural Roads</td>
<td>0.95 M €</td>
<td>9.766 M €</td>
</tr>
<tr>
<td>Urban Roads *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL KM</td>
<td>29.160</td>
<td>41.963 M €</td>
</tr>
</tbody>
</table>

Annual Expenditure 427 M €**

Annual Value Loss

* Urban roads included in national, regional and rural roads
** Financial funds, provide for approx. 60% of maintenance standard

Regarding the construction value per km, figures are sometimes available only for motorways and national roads (Belgium, Denmark). Some other countries provide only values for motorways and national roads on one side and other types of roads on the other (Germany).
But most concerning is the fact that almost no country is able to provide values of maintenance expenditures. When figures are available, no distinction is made between ordinary and extraordinary maintenance and no specific information is available on where this investment is made (surface, equipment, markings…)

Summarising the situation, we can say that, in general terms, the responsible authorities or road owners don’t really have an idea of the value of their roads, and even less about the money spent for its maintenance!

Our main objective was still to make an estimation of the value of the road asset in Europe. On the base of the information received, we estimated the average construction value of a km of motorway at some 10 Million €, and we chose a (very conservative) figure of 1.5 Million € of construction value for each km of any other kind of road.

This resulted in an estimated value of 8 Trillion € for the European road infrastructure.

4.4 The Manifesto

Following step in the activities of the WG on RAM was the publication of the Manifesto, a document aimed at raising awareness of policy-makers on the issue of the importance of the Road infrastructure as an asset and the necessity to maintain it properly.

The development of the Manifesto was carried out according to the following structure:

- title: ‘A Manifesto for a long-term, effective management of a safe and efficient European road network’
- some facts and figures
- identification of the problem:
  - the lack of knowledge of the value of the road asset
  - the lack of investment for its maintenance
  - its irreversible deterioration
- the description of the solution: the Road Asset Management principles and the life cycle approach
  - inventory and estimation of value and maintenance requirements
  - prioritisation of interventions and funding scenarios for regular and timely maintenance
  - help on establishing cost-effective programmes
- policy recommendations
  - recognise of the benefits delivered by roads to society
  - provide mobility for the future
  - raise awareness about the real value of roads
  - inform road users
  - support road authorities to use RAM
  - take necessary political decisions

5 http://www.erf.be/images/Road_Asset_Management_A_manifesto_to_keep_Europe_moving.pdf
4.4.1 The life cycle approach

Regarding the part of the Manifesto dedicated to the solution, or better said the Road Asset Management principle, it is important to have a closer look at the selected approach, i.e. the Life Cycle Approach. Beyond the mere aspect of asset value, it is important to consider the road infrastructure through its whole life cycle. The approach must be systematic and take into account all the stages of the life of the roads, from the conception and design, the construction, upgrading, operation and maintenance, to the replacement phase, if necessary. When the priority is given to the construction aspect, the initial investment has also to be considered with a longer term perspective, already taking into account the different phases to which the infrastructure will be submitted during its life time. Every stage requires a proper, sufficient and responsible fund allocation.

The table below displays a typical development of the value of the road capital (or asset) along the time.

<table>
<thead>
<tr>
<th>Time</th>
<th>Value</th>
<th>Investment in road capital</th>
<th>Deteriorations models and yearly defect registration.</th>
</tr>
</thead>
</table>

It clearly indicates that the value of the road decreases with the time, until a certain investment is made in order to restore or increase the asset value, followed by a progressive loss of value. This cycle is continuous. Through the whole life cycle of the road, any lack of investment has impact on the economy (loss of value), the safety (degradation of the infrastructure and its qualities) and the environment (major degradations can lead to increased congestion and urgent major road work interventions can generate traffic disturbances increasing bottleneck effects, causing congestions and increasing the level of CO2 emissions).

With limited budgets available, the only solution is to carry out a global analysis of the condition of the road infrastructure, identify the priorities and make the necessary decisions for prioritizing funding, where the best return on investment can be found, while preserving and even increasing the asset value of the road infrastructure. This is the only way to maintain the necessary level of safety, mobility, sustainability and service to the road user.

Investing in the road infrastructure is the most effective type of investment, for the preservation and the improvement of the road asset value, but not only for financial purposes. It has essential and immediate impact on safety, too. The following table displays the major causes of accident on roads, which are related to road conditions. Improving the road condition improves safety.
Easy and quick to implement solutions, by investing in the road infrastructure, can help reduce fatalities and increase safety and service to the users.

In the Netherlands, the Institute for Road Safety Research (SWOV) produced a report entitles ‘The Balance Struck: Sustainable Safety in the Netherlands 1998-2007’ that evaluated the national road safety programme’s success. During this period, the number of accidents decreased in total by 30%, decreasing in real numbers from 1149 to 791. This resulted in more than 1700 lives saved as a result of the new measures. This reduction was achieved by an annual investment of approximately 530 million € spent for road safety measures, 350 Million € of which spent on road infrastructure. Assessing the cost-benefit ratio of the measures, the report concludes that measures were socially cost-effective, with a cost-benefit ratio at 4:1. (« De balans opgemaakt : Duurzaam Veilig 1998-2007 », SWOV, 2009, http://swov.nl/rapport/Balans_10_jaar_DV.pdf)
4.5 The ERF Position paper on RAM

Further to the publication of the Manifesto and its presentation within the EU institutions, it appeared that the issue of the loss of value of the road infrastructure is widely ignored by policy and decision makers at all levels. This encouraged us to pursue our activity on RAM and to then publish a Position Paper, with more in-depth information on RAM. This Position Paper aims at explaining the instruments available for efficient Road Asset Management, by identifying and presenting best practices and their benefits for the society.

Among other things, this Position Paper details the different steps of the process of implementation of a RAM strategy, from the necessary complete inventory of all roads elements, their value and their current condition, through the incorporation of future requirements, the setup of priorities and appropriate funding scenarios, to the implementation of the RAM plan. It is to be noted that this process is permanent and requires systematic monitoring.

At European level, it is interesting to note that during the last TENT days conference, which took place in Riga on 22\textsuperscript{nd} and 23\textsuperscript{rd} June 2015, the European Commission has clearly highlighted the necessity to support the necessary financing of the transport infrastructure in the future.

In their Action Plan for the development of transport infrastructure project financing, the EC lists a series of 12 recommendations. The 3\textsuperscript{rd} one says that ‘Project promoters should include and pay, in the project preparation process, due consideration to the projects’ life-cycle from project conception to development and implementation, including the costs and all other relevant issues linked to their maintenance’. This is the first time that the issue of maintenance is clearly indicated and highlighted as a strong recommendation in the EC plan. We can only welcome and support this decision.

Another future development of the ERF WG on RAM is to disseminate the concept of RAM through new channels, such as Social Media. The ERF has recently launched a European Social Media platform (European Road Initiative / e-motion) to improve the communication between the European Road Infrastructure sector and the general public.

Another important direction taken by the WG on RAM is to reinforce the cooperation with other international organisations which study Road Asset management, such as the International Road Federation (IRF), but also the International Transport Forum (ITF) and the Organisation for Economic Co-operation and Development (OECD). During the last 6 months, the Chairman of the ERF WG on RAM, Mr. Stefan Gervens, has actively participated to a Joint Task Force initiated by the ITF and the OECD, gathering representatives from the Industry and international organisations such as ERF, the European Investment Bank (EIB) … to improve the knowledge on Investment in Road Infrastructure and the quality of information available (harmonised data on assets by asset types, conditions…), and develop a methodology for making comparable estimates on investments levels.
5. CONCLUSIONS

Road networks represent one of the most important assets for the community. Strategic asset management is a key to understand needs, vulnerabilities and trade-offs. In connection with long-term financial planning, sustainability for sources of funding is an essential element to maintain performance and preserve the asset, and will help providing the optimization of the service level delivered over the life-cycle of the infrastructure.

Under tight budgets, road maintenance is often postponed; in reality costs for road maintenance are much higher than what they should be due to deferred maintenance, which increases debt but also asset vulnerability to disruptions. It is essential to quantify the costs of underfunding the infrastructure and make decision makers aware of this situation.

The quality of transport infrastructure is a key determinant of performance in the transport sector. Countries spend considerable amounts of money on transport infrastructure and yet, data on spending and assets are often lacking. This can lead to decisions based on partial information.

An improvement of data on investment and existing assets will lead to a better analysis and benchmarking for supporting decision process on road infrastructure investment, by prioritizing them, assessing the existing condition and compare the infrastructure performance.

This requires a better comparability of data analysis at international level. The concepts of Road Asset management must be widely spread at different decision-making levels (International, European, national and local), with clear evidences of the benefits of the RAM approach and principles. The information provided must also include best practices and concrete examples of RAM solutions successes.

This also requires a strengthened cooperation between international institutions and organisations which study the issue of investments in transport and road infrastructure and want to develop the concept of RAM. This can be made through joint task forces, organisation of dedicated events, seminars, conferences and workshops. We therefore encourage other organisations to join us for achieving this process.

This information should also be made available to the road users. The value for road user should be the primary focus and some innovative channels such as Social Media can be an interesting tool for a larger dissemination of this information.

Acknowledgements

- Mr. Stefan Gerwens, Chairman of the ERF WG on RAM for his continuous dedication to the WG activities
- Mr. Simon Vanderbyl from EAPA, for his input and support in the production of the ERF Manifesto on RAM
- Mr. Jari Kauppila from ITF for his kind offer of ERF participation to the OECD Joint Task Force on ‘Measuring Infrastructure Spending and Assets’
Establishing Optimal Long Term Funding Allocation Systematic Approach based on Network Needs & Availability of Funds

By

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Word Count: 5,649
1 RESEARCH HYPOTHESIS

“A tool, will be created, suitable for all levels of road administration, to provide the cost and level of service of a road network for a multiyear plan as a function of Deterioration, Budget and Political Influence designed to evaluate the impact of changes to budget or level of service or both”.

The key element of this research study is to develop a model by multi-criteria analysis with a deterministic outcome and a model based on preferential analysis to determine optimality. The data will be summarised in templates and imported from various sources into the system tool, however data must be harmonised and to be synchronised to ensure compatibility with output files.

This research will be unique in that it will provide the road network owner’s viewpoint and be driven by value for money whilst meeting the fundamental principles of sustainability, innovation, and risk management. The following graph illustrates research hypothesis.

Keywords: Asset Management, Funding Allocation, Budgeting Framework, Allocation Mechanisms.

2 INTRODUCTION

Road Controlling Agencies (RCAs) around the world are facing continuous challenges sustaining network funds. Given the fluctuation of market forces and instability of economies around the world. Effective management of a roading network requires that levels are set at least sufficient to keep the core of roading assets in a stable condition for long term. This requires that ongoing maintenance is funded, and that adequate provision is made for any strengthening works required. More than this minimum level will be required if the network is to be expanded or improved. Roads are usually funded through budget allocations determined as part of the annual government budgeting process.

Roads with different hierarchies and functional classifications may be managed by different road administrations. Sometimes they will have their own sources of funds (investments). For others, funding will come from the national sources. Particularly for roads of lower hierarchy, the provision of funds will often be shared between national and local / regional sources. It is common for central governments to fund all work on national or trunk roads. In all cases, mechanisms need to be in place for allocating and disbursing funds between the different administrations. They need to be simple, transparent and encourage consistency of standards between the different administrations. Example case and a reference made for some of the elements described in this paper from Abu Dhabi as the researcher is currently working over there.
3 BUDGETING ADMINISTRATIVE FRAMEWORK

Modern budgeting systems were developed as a means of exerting legislative control over resource allocation decisions by the executive. This was achieved by dividing responsibility for and authority over the resource allocation process between institutions whose competencies and relations were defined in law, supplemented by exhaustive rules and procedures.

<table>
<thead>
<tr>
<th>Ministry of Finance</th>
<th>Responsible for the management of public expenditure, including the formulation of a consolidated state budget and accounts, and the management of government’s cash resources.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spending Agencies</td>
<td>Responsible for the planning, management and delivery of public services, and the preparation and management of agency budget. Spending agencies are usually headed Ministers, occasionally by public officials.</td>
</tr>
<tr>
<td>Cabinet</td>
<td>Collectively formulates government policy. Implementation of government policy is the responsibility of individual Ministers. Cabinet approves the Government’s budget.</td>
</tr>
<tr>
<td>Legislature</td>
<td>Analyses the Government’s budget proposal and accounts, through the work of specialist committees, and enacts the budget in law. In Congressional systems, the legislature may amend the Government’s budget proposal. In Parliamentary systems, it usually may not.</td>
</tr>
<tr>
<td>Auditor</td>
<td>Verifies compliance with the budget law and procedures regarding the use of public funds. The Auditor usually reports directly to the legislature, though in some cases may be considered part of the Ministry of Finance and report to Government through the Minister.</td>
</tr>
</tbody>
</table>

4 STRATEGIC BUDGETING

Roading administrations in emerging economies such as the Department of Transport (DoT) in Abu Dahbi, are increasingly operating under a unified budget provided and approved by the Executive Council. There is no distinction between “Capital and Operational” or any other budget categories. A lump sum budget is awarded and decisions on its expenditure between different types of works are made by the road administration itself on the basis of policy framework or needs; Robinson R, Danielson U and Snaith M (1998). Local budget categories may be used to assist in managing funds. While a unified budget will enable the needs of the network to be considered as a whole, the possibility of optimizing expenditures may not be optimal and could vary year by year. This research proposal focuses upon the breakdown of roading budget categories, which will subsequently be used to determine a unified lump sum.

5 LINKING BUDGETS TO BUSINESS OBJECTIVES

When the revenues available to the road sector are significantly less than the amount required to maintain the road network in a stable long-term condition and to undertake justified improvements, the road agency should prepare an explicit long-term financing plan showing the size of the financing gap and the options for bridging the deficit. If a financing gap is indentified changes to the financing plan should also include strategies to reduce the shortfall. The objectives need to consider the scope for increasing the revenues available to the road sector by simplifying road user taxes. Other possibilities include restructuring the taxes, reducing tax avoidance, evasion and leakage; Heggie, I G (2000). This research should assist to in closing the gap and creating a systematic process in a wide range of scenarios.

6 IMPORTANCE OF RESEARCH

The research will develop a new approach to the allocation of all resources (finance, natural, manufactured, and human), within a budgetary framework which has a function of various operation and renewal scenarios.

The research will provide a system tool for assessing fund forecasts considering various scenarios. This system will be flexible and can be adjusted to provide a confidence to the road authority and government on needs verses available revenue. The system also will assist the government funding agency to compile and integrate funding request from various authorities to optimize fund bids.
THE OBJECTIVES OF THE RESEARCH

This research will design and demonstrate the implementation of an optimal road funding system tool that will assist in predicting long term roading infrastructure financial plans. The research will deliver a system tool which:

- Is suitable for an international marketplace (e.g. The World Bank, Investment Authorities) and be applicable to advanced and emerging economies;
- Is compatible for large and small infrastructure networks managed and funded by local, regional, and central governments;
- Can make a positive contribution to the technology for funding maintenance management of road networks within the road reserve;
- Is open, flexible and can be customised according to network characteristics. A multi-objective optimisation process capabilities will also be incorporated.

RESEARCH LITERATURE REVIEW

It is important to differentiate between financing and funding. The term funding, as used in this research, refers to how infrastructure is paid for. Ultimately, there are only two sources of funding for infrastructure, government investment or direct user charges. This is opposed to financing, which refers to the way in which debt and/or equity is raised for the delivery and operation of an infrastructure project.

The budget process has two principal components:

- To decide how much funds are needed;
- To decide how to allocate the funds those are actually awarded.

Usually, budgets are allocated on an annual basis, a typical budget process might be summarized as follows,

- There is an initial call from a Finance Authority or Ministry to submit bids;
- Spending authorities respond;
- Subsequently the Finance Authority consolidates and reviews the submissions within overall spending targets;
- Government authorities may be called to support their submission during this process;
- Draft estimates are then published and are submitted to elected members of the government for approval, (in the case of Abu Dhabi, the Executive Council) will be the approving authority;
- Following this, a warrant for a given amount is issued to relevant authorities, so that spending may commence at the start of the new financial year.

Under such arrangements, therefore each authority competes for funds and at least in theory, funds are allocated to finance those expenditures with highest economic or social return, however such allocation are invariably highly politicized and allocations are often far from economically optimal. Politicians at national level are more likely to reflect general social needs than at the local level, where vested interests tend to have greater influence. Expenditures for maintenance, in all sectors inevitably lose out to higher profile capital investment projects, which contribute to the under funding of roading maintenance, as a result roading maintenance expenditures are often based on historical precedent; each year’s budget is based on that of the previous year, with an additional allowance to cover inflation. This is a limited and poor basis for budgeting since it is arbitrary.

A better robust approach is for the budget application to be assessed on a rational assessment of economic need that relates to the objectives specified in the policy framework. One approach to the needs-based budgeting is for budgets to be based on life cycle costs, upgrading and reconstruction costs and road users costs over the life of the road by choosing the optimal level of maintenance. If roads are maintained too soon, then the full value of the existing pavement will not be attained and maintenance costs will higher than any reduction in operating costs, hence, total transportation costs are higher; conversely, if roads are maintained too late, the consequent maintenance will be more expensive or the value of asset may be lost. Therefore, the standards and intervention...
levels specified in the policy framework should reflect the need for maintenance. If there is to be consistent within the policy, the road maintenance budget, then the cost of the work needed to correct defects should be funded by the budget. Some Road Funds are committed to a fixed percentage allocation but this is not necessarily the best solution, and cannot always be affected anyway; Chan W T, Fwa T F, ASCE M and Tan J Y (2003).

A review of the funding allocation process used in a number of countries around the world has been undertaken, such as New Zealand, Australia, North America, Europe, Asia and Africa, it important to note, while this review may discuss how the government funding agency distributing the fund, the reality compiling a bid by the authority reflecting how detailed or a sophisticated process being used by the funding authority. Detailed literature review including references is available however due to limitation of paper submission, only a summary with key highlights are provided.

9 OPTIMAL PRACTICE WORLD WIDE – SUMMARY REVIEW

For efficient and consistent allocation of monies, priorities should be on the basis of economic cost-benefit principles, selecting those projects that demonstrate the highest economic rates of return. In practice the task is not that simple. Political interests may impose certain regional allocations, and rural roads need to be justified on the basis of other criteria because their economic case will inevitably be weak. The process of allocating monies between types (trunk, district, urban and rural or feeder) is a continuing problem that has not been satisfactorily been resolved. Some Road Funds are committed to a fixed percentage allocation, but this is not necessarily the best solution, and cannot always be affected anyway.

Resource allocation decisions are made unilaterally by the Ministry of Finance. In many cases, however, allocations are made in consultation with the Ministry of Transport. The consultation process can assist the Ministry of Finance in determining the appropriate total level of funding to be made available for road and bridge improvements. This determination must consider a total maintenance and rehabilitation requirements to support the desired level of overall system condition and performance for the country road and bridge systems.

10 BUDGET CATEGORIES

Budget Categories, the financial provision of roading network in many countries is divided into:

**Capital (Capex)** which relate to the construction of new roads, and sometimes the reconstruction, rehabilitation, strengthening and resealing or renewals of existing roads;

**Recurrent (Operational)** – the other category is a provision for the regular maintenance of the existing roading network, such as surfaces, off carriageway features, and for dealing with various contingencies, staff cost may also be paid under this category.

Sometimes the strengthening and renewals may be paid within the recurrent budget. In some roading agencies, the budget categories have breakdowns into more details such as a budget to maintain road structure, corridor maintenance, drainage facilities etc.

Where budgets awarded under different budget categories are usually less than bids for the roading agency, this means a lack of ability to vary funds from one budget category to another and will prevent the optimal allocation of resources under overall budget constraint.

11 ALLOCATION MECHANISMS

Roads with different hierarchies and functional classifications may be managed by different road administrations. Sometimes they will have their own sources of funds (investments). For others, funding will come from the national sources. Particularly for roads of lower hierarchy, the provision of funds will often be shared between national and local / regional sources. It is common for central governments to fund all work on national or trunk roads. In all cases, mechanisms need to be in place for allocating and disbursing funds between the different administrations. They need to be simple, transparent and encourage consistency of standards between the different administrations. Three basic methods are commonly used for:
Simple Allocation Formula;
Indirect Assessment of Needs;
Direct Assessment of Needs.

Simple allocation formula assigns funds on the basis of pre-defined percentages to different parts of the network. Such allocation mechanisms are simple and transparent, but over time, are related only weakly to current need or use of the network.

Indirect assessment of needs; is used where there are no reliable data for measuring need directly or where the cost of doing so would be disproportionate to the size of the budget being allocated. This method is used mostly for the allocation of budget to low cost/low volume roads, criteria used in the indirect assessment will include for example;

- The land area covered by the administration;
- Road density;
- Population;
- Industrial / agricultural production or potential.

These factors are weighted accordingly to their perceived importance, this approach provides a pragmatic basis for allocating funds in appropriate cases that is cost – effective, and acknowledges the socio-political aspects of the decision-making.

Direct assessment of needs; can be of different degrees of sophistication, as its most comprehensive, it will involve using the results of a detailed condition survey of all needs to determine work requirements. These are then costed to derive the budget requirement. This approach requires the use of treatment selection methods such as deterioration modelling.

Simpler methods; involve deriving norms for expenditure on roads in different hierarchies or of different surface types. Road lengths in each administration are simply multiplied by the relevant norms to give the budget allocation. Thus, there are several direct assessment methods. The methods chosen should suit the capacity of the level of government concerned. The key is to have clear objectives and then to appraise in a systematic way the extent to which each intervention contributes to realizing these objectives. It is often difficult to change existing allocation methods because there will be strong resistance from those who will lose out “political interest”. There may also be pressures to maintain a “regional balance” that may actually distort the optimal allocation of funds.

12 PRACTICAL BUDGETING TECHNIQUES

The purpose of resource allocation is to determine the appropriate total level of capital and maintenance investment that is to be made available for road repair and rehabilitation, bridge reconstruction and rehabilitation, and new construction, usually on an annual basis. Distribution is the manner in which total funds allocated for highway and bridge repair are made available to sub-national jurisdictions, road systems, and types of improvement.

Six identifiable patterns of resource allocation can be identified. The defining characteristic of these six patterns is the degree of shared responsibility between the Ministries of Finance and Transport (or their equivalents) in the allocation process.

In the first pattern, the responsibility for allocation, especially for the national road system, is retained in governmental hands. For example, the Ministry of Transport in Canada is totally responsible for resource allocation on the national road network. In Great Britain, the Department of Transport has the responsibility on a central as well as on a regional level. The procedure for resource allocation in the United States is very much reflected by the interaction of responsibilities between the Federal and State levels. In New Zealand, the government funding agency (NZTA) taken a leading role in allocating and distributing funds.

In the second pattern governmental jurisdictions are still in charge of allocation, while the distribution procedures are transferred to national, regional, and local road administrations. Germany, Japan, Norway, Portugal, Spain, and Switzerland belong to this allocation/distribution category.

In the third pattern, autonomous bodies are involved. This describes the allocation/distribution process in Italy, with the Autonomous State Roads Administration (ANAS).
Finland and Sweden represent the fourth discrete pattern. Although the financial responsibility remains in the hands of the government, the Road Administrations have a strong impact. This is consistent with the "management by objectives" philosophy that these countries have adopted.

The fifth pattern related to wealthy governments (economy based on oil & gas revenue) such as the case in Abu Dhabi, the financial approval issued by the Executive Council, the political decision basically controls the funding allocation and distribution.

The sixth pattern, developing countries, the overall planning process appears to be inconsistent and very far from optimal in meeting some sensible framework of objectives.

Typically, the Central Government generally defines the total annual roadway rehabilitation and maintenance budget. In addition to the initial budget allocation, the central government may also determine the distribution of those funds by governmental jurisdiction, road system and, in some cases, by major category of road improvement type, although the involvement of the central road authority varies by country.

Decisions are made using a combination of technical analysis to achieve efficiency in fund allocation, and political, social, technical and economic considerations to achieve funding equity and balance among competing interests and political jurisdictions. This combination of technical and political considerations appears to exist in some fashion. As was true with the degree of central government involvement in the allocation process, however, the variations among countries in the relative mix of technical and political considerations are broad.

Under the political level(s) the managing responsibilities of road administrations differ between countries. Some countries use "management by objectives", "directed autonomy", or "zero based budgeting" philosophies in carrying out their responsibilities; other countries are more directly tied to the Ministry of Transport which permits only "limited autonomy" to their road administrations.

### 13 PROBLEM STATEMENT

Roads are usually funded through budget allocations determined as part of annual government budgetary processes. Roading related budget allocations often bear little relationship to the levels of funding that contributes to revenue or the underlying needs of the network provided for by the road users. This is measured in terms of economic criteria and consequently there is no direct linkage between revenue and expenditures. This research focusses upon Abu Dhabi where the network is growing rapidly and will continue to over at least the next 10 years. Moreover, the quality of final deliverables and new vested assets in this location require immediate maintenance and additional operational expenditure. Therefore there is a need to establish a robust long term assessment tool that caters for maintenance and operational requirements. This research argues that this assessment should be based on life cycle costs throughout the useful life of the infrastructure.

Funding for roading networks traditionally comes from governments (which is the case in Abu Dhabi - United Arab Emirates). It becomes increasingly more difficult to maintain road funding at past levels, one of the reasons is that typically roads are seen as a common good and funded as a social service.

### 14 RESEARCH QUESTIONS

The key research questions which relate to international roading networks are:

- How much expenditure does the current network need?
- How do we allocate funds to a network? What would be the optimal fund allocation?
- What are the key components of a budgetary assessment for network operation and maintenance?
- How are network needs predicted? How are credible budget requirement assessed?
- What is the confidence level of a budgetary bid?
- How do we correlate and justify a budget request versus allocated funds?
- What are the risks associated with the current level of funding?
- What certainty can be given to a budget level compared to the required level of service?
- What will the road fund finance? Where will the revenues come from?
- How will the road fund be set up?
- How can one ensure good governance? Who will manage the road fund?
• What powers will the Government have in relation to the fund, will special penalties apply for misappropriation of funds?
• What funds are needed to acquire, operate maintain and renew the asset?
• When will funds be required?

15 RESEARCH CONCEPT

The initial overall determination of budget allocation performed by the Ministry of Finance may be considered systemic in nature. It requires an objective and subjective evaluation of alternate investment strategies against a prescribed set of national or regional goals. In some cases, the initial distribution of funds by highway system and jurisdiction to achieve equity also involves measurement against these same or similar objectives.

Systematic measurement and evaluation requires the development of standardized data and analytical procedures to ensure that comparisons are accurately made throughout the nation's regions or provinces. The types of data required for this initial allocation are general in nature. They consist of measures of system usage and extent, land area, population, and other objective measures of a real dimension, as well as standard network measures that can be applied nationwide.

These requirements are defined within a strategic planning matrix arrived at through professional judgment, active consultation with districts within the country, or a combination of the two methods.

The essential difference between these comprehensive resource allocation strategies and the strategies typically used today is that standard resource allocation is a marginal process. Past year allocations are used as a baseline for comparison against possible budget options and evaluations are made on the basis of marginal changes in allocation and distribution. Under the more comprehensive method, budgets are "built up" on the basis of how well an allocation level or means of distribution achieves a prescribed goal or objective. The baseline seems to be a critical issue to Abu Dhabi, as the network is growing rapidly with increasing demand.

The distribution by type of road improvement is a rigorous engineering and/or economic analysis, requiring the use of sophisticated computer programmes that relate investment to system performance impacts. In most cases, distribution analysis is sufficiently sophisticated to relate investment to changes in measurable engineering parameters such as pavement and bridge condition, safety, or levels of service.

The quality, consistency, and application of complex road and bridge databases and analytical systems (asset management) to support the development of rehabilitation and maintenance budgets vary widely among participating countries. This information may include measures of roughness, deflection, rideability, and/or surface cracking. This information can be used to establish bearing capacities to support the development of pavement management programmes.

On the other hand, drainage adequacy and subbase condition is seldom available, and these are major factors that help determine the particular type of pavement rehabilitation strategy required for accurate life-cycle pavement cost estimation. In addition, future travel forecasts, particularly by vehicle category and subcategory.

This move toward consistency requires the development of standard techniques and data systems, within the context of a fully integrated road and bridge management system. The system should be capable of accommodating the types of allocation and fund distribution currently required, including:

• Development of budget totals based on relating expenditures to changes in overall system performance;
• Development of regional distributions through the use of economic analysis that equitably
• Compares the overall value of the investment by jurisdiction; and
• Development of functional distribution tools to calculate and compare changes in road user costs associated with various investment strategies.
16 PROPOSED FRAMEWORK

The conceptual framework of the proposed system is outlined below:

<table>
<thead>
<tr>
<th>Process</th>
<th>Function Requirements</th>
</tr>
</thead>
</table>
| **Input Data**                 | • Define asset data type  
|                                | • Network condition prediction data &  
|                                | • Forward works programmes  
|                                | • Asset valuation & economic efficiency determination  
|                                | • Maintenance cost data  
|                                | • Annual budget considering split (Capex vs Opex)  
|                                | • Work categories definitions, classification of activities  
|                                | • Develop and prepare integrated input file                                                      |
| **System Matrices Setup & Global Values** | • Key analysis factors  
|                                | • Infrastructure Development Index  
|                                | • Budget configuration; operation, maintenance, improvement, new and reconstruction  
|                                | • Calibration of analysis matrix  
|                                | • Infrastructure gaps  
|                                | • Funding assistance rate  
|                                | • Development of Risk Matrix values & risk profile graph  
|                                | • Project implementation performance  |
| **Analysis & Budget Scenarios** | • Validation of input data (out of range)  
|                                | • Performance-Based Allocation Formula  
|                                | • Economic and customised analysis  
|                                | • Aggregate data into bands  
|                                | • Budget Categories, Approved with Condition, committed allocation  
|                                | • Summarisation of maintenance cost  
|                                | • Perform scenario analysis  
|                                | • Programme review and variations  |
| **Optimisation**               | • Definition of critical optimisation factors such as strategic fit, the effectiveness and the economic efficiency  
|                                | • Budget distribution per category  
|                                | • Alignment of infrastructure projects  
|                                | • Budget scenarios vs. condition  
|                                | • Optimisation vs. committed programme  |
| **Outputs**                    | • Final outputs (multi scenarios)  
|                                | • Multi-year forecast of expenditure by activity class  
|                                | • Minimum allocation  
|                                | • Reporting (default, customised, summary, per asset type)  
|                                | • Capex vs. Opex distribution  
|                                | • Optimal scenarios  
|                                | • Audit (review allocated vs. actual resources)  
|                                | • Category review  
|                                | • Trends (increased / decreased) and future spikes  |

17 SOFTWARE PLATFORM

The research study and the development of the software tool will advance simultaneously as part of the research project. The research also intends to carry out a pilot testing to ensure a smooth implementation.

**System Architecture**

The system architecture is depicted in the following chart.
Proposed Architecture to Implement System Tool

Input
- Asset Types & Classification
- Asset Valuation & Maintenance Cost Data
- Define Budget Scenarios
- Various Databases NMRS, BMS, FWP
- Defaults & Calibration Factors
- Validation & Synchronisation Input file

Analysis
- Economic Analysis
- Performance Analysis
  - Network Needs
  - Run & Get Results
- Customised Analysis

Optimisation
- Define Optimisation Factors
- Optimisation Process
- Sensitivity Analysis

Output
- Review & Audit
- Optimised Budget Scheme
- Various Report
- Minimum Budget Allocation
18 THE WAY FORWARD

The following screen shots illustrate the front end of the system that is currently under development. This front end of the system reflects the research findings to date. The system platform will be based in various data sources such as valuation, predictive modelling, long term & annual plans together with other source of data. More details will be presented during the conference as the study is progressing and further outcomes are achieved.
ACKNOWLEDGEMENTS

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21 BIBLIOGRAPHY

Biographical note for Alan Roland

Alan is a Chartered Professional Registered Engineer of New Zealand (MIPENZ), (CPEng), (IntPE) and REAAA. Member of INGENIUM (Association of Local Government Engineers of New Zealand). Alan holds a bachelor degree in Civil Engineering, and Masters Degree in Transportation Asset Management. He has experience almost 30 years in transportation asset management at both strategic and operational levels; infrastructure development, design, operation and maintenance; development and implementation of road asset management processes and systems. Alan presented a number of asset management papers at the national and international workshops and conferences.

Alan has been working with government agencies, consultants and contractors, and currently is working with the Department of Transport in Abu Dhabi, as the Network Inventory and RAMS Specialist. Alan is currently a PhD candidate and currently working on this research.

Biographical note for Mark Porter

Mark Porter is a Professor of Engineering at the University of the Sunshine Coast, where he is responsible for the development of new teaching and research programs in Civil and Mechanical engineering. He is a water resource and environmental engineer with a strong interest in engineering education and a background in research, teaching and academic management. He is now overseeing the development of new research programs in asphalt pavement engineering, permeable pavements, and the impacts of climate change on coastal infrastructure.

Mark's achievements include a university Excellence Award for Research (1993) and an Excellence Award for the Design and Delivery of Teaching Materials (2003) and a national Carrick Award for outstanding contributions to the Enhancement of Learning (2007 - Learning and Teaching Category: joint winner). He is a Fellow of the Institution of Engineers and held the position of Chairman for the Sunshine Coast Local Group of EA in 2012-13.

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Professor John Yeaman FTSE, PhD, FIE (Aust) CPEng, RPEQ is the Director of The Queensland Functional Pavement Centre at the University of the Sunshine Coast and Professor of Civil Engineering Construction.

John has been in the Civil Engineering Materials and Paving industry since 1957 directly involved in new and innovative products and services for 25 of those years. He built his own business in Pavement Management in which he was the principal engineer for 30 years.

For the past 3 years his has been an academic heavily involved in Pavement design, construction, operation and renewal maintenance, contract management and project management.
PAPER TITLE: Asset management and performance management working together

TRACK: C.1 Management of Road Infrastructure Assets

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ABSTRACT:
The best way to define the working relationship between asset management and performance management is to recognize that a transportation system’s performance, how well the system provides for the safe, efficient, and environmentally responsible movement of people and goods, depends on many factors including usage and demand, capacity, system operations, user behavior and many other factors in addition to the physical condition of facilities (pavements, bridges, and other infrastructure assets).

Performance management is a strategic activity that focuses on how policies, resource allocation and other decisions affect all aspects of system performance including safety, operations, environmental stewardship and infrastructure condition. The basic principles of performance management can be applied to all aspects of transportation system performance and to the performance of transportation agencies as well.

Asset management refers to applying performance management principles to the management of transportation physical assets and provides a strategic approach for the maintenance, preservation, rehabilitation, and renewal of these assets. Asset management is one of the most advanced examples of the application of performance management principles in the transportation industry. The analytic tools, data, and experience in applying performance management principles are more advanced in asset management than in many other aspects of transportation.

This presentation will highlight the relationship between asset management (AM) and performance management (PM) and describes how managing assets within a performance based environment can help agencies become more strategic in their decision making process for project selection and resource allocation.
1 INTRODUCTION

Performance Management is the on-going system of establishing strategic goals, objectives, and performance measures for an organization, monitoring progress on achieving the goals and objectives, and making decisions based on performance data to ensure achieving the goals and objectives.

The Federal Highway Administration (FHWA) Office of Transportation Performance Management defines Transportation Performance Management as a strategic approach that uses system information to make investment and policy decisions to achieve a desired set of national goals.

The American Association of State Highway Transportation Officials (AASHTO) Subcommittee on Asset Management has defined Asset Management as a strategic and systematic process of operating, maintaining, upgrading and expanding physical assets effectively through their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well defined objectives.

Performance Management covers all aspects of the business of a transportation agency. Asset Management is a subset of the overall performance management system that is related to the physical infrastructure. Asset Management is a highly developed form of Performance Management that is intended to achieve the most cost effective long-term levels of service for the physical infrastructure for present and future customers.

At a minimum, Asset Management applies performance principles for the long-term cost-effective maintenance, preservation, rehabilitation, and reconstruction of the physical assets. At its fullest, Asset Management also applies performance principles to the long-term cost effective preservation of physical assets to enhance their value, preserve, renew, and enhance them for the lowest reasonable lifecycle cost so they provide the needed level of service to meet mobility, safety, environmental and economic objectives.

Asset management is a framework being widely accepted as a means to pursue and achieve sustainable infrastructure. A high-performing asset management program incorporates detailed asset inventories, operation and maintenance tasks, and long-range financial planning to put the infrastructure systems on the road to sustainability.

The best way to define the relationship between asset management and performance management is to recognize that a transportation system’s performance, how well the system provides for the safe, efficient, and environmentally responsible movement of people and goods, depends on many factors including usage and demand, capacity, system operations, user behavior and many other factors in addition to the physical condition of facilities. Performance management focuses on how policies, resource allocation and other decisions affect all aspects of system performance including safety, operations, environmental stewardship and infrastructure condition. The basic principles of performance management can be applied to all aspects of transportation system performance and to the performance of transportation agencies as well.

Asset management is one of the most advanced examples of the application of performance management principles in the transportation industry. In fact, much of the initial work on defining the core principles of what now is called
performance management grew out of AASHTO and FHWA efforts to promote a strategic approach to asset management. The analytic tools, data, and experience in applying performance management principles are more advanced in asset management than in many other aspects of transportation.

Because most transportation facilities have long service lives, asset management must have a long-term focus. Many asset management programs focus primarily on pavement and bridge condition using performance measures that reflect all the key metrics related to the physical health of these facilities. However, there are other physical assets that support a range of performance goals that need to be incorporated into a comprehensive asset management program. These other performance goals include safety (lighting, signing, marking, guard rail, median cables, rest areas, etc.), operations (traffic signals, traffic management centers, incident response equipment, etc), traveler information (call boxes, variable message signs, 511 systems, etc.), as well as other support facilities and equipment.

Over the past few years, much progress has been made in applying performance management principles to many aspects of performance, beyond the physical condition of assets, including operations, safety, congestion relief, system reliability, environmental concerns as well as key elements of organizational performance such as project delivery and customer service. In these cases, performance measures would vary widely from travel time and delay for system operations to fatalities for safety and on-time/on-budget delivery for projects depending on the focus of the performance management effort. While some of these broader aspects of performance management (e.g., congestion relief) might also be long term in nature, other aspects, including system operations (e.g., incident response, real time system management, etc.) may be more short-term oriented.

In summary, the core principles of performance management apply to all aspects of transportation system performance. Asset management applies these principles to the physical condition of infrastructure, vehicles, and all other facilities and equipment used to operate and manage the system so they provide the needed level of service to meet mobility, safety, environmental and economic objectives. Even though asset management principles can be applied short-term, it is most effective when implemented considering long-term goals and objectives. The specific application of performance management principles to different aspects of transportation system performance vary in terms of the appropriate performance measures, short-term versus long-term focus, the appropriate strategies for improving performance and the timeframe for being able to observe performance changes.

2 PRINCIPLES OF PERFORMANCE MANAGEMENT AND ASSET MANAGEMENT

Figure 1 shows the basic elements of performance management. At the broadest level, performance management links agency goals and objectives with resources and results.

![Figure 1. Performance Management Framework](image)

*Linking Goals/Objectives to Resource and Results*
Each of these performance management elements apply to asset management and the other aspects of transportation system performance as discussed below:

- **Goals/Objectives** – Resource allocation and other decisions are based on a well-defined and explicitly stated set of policy goals and objectives. In the case of asset management, these goals focus on the desired long-term condition of pavements, bridges, and other physical assets. For other aspects of system performance, goals focus on safety, operations, other performance areas, as well as agency performance such as project delivery.

- **Performance Measures** – Policy objectives are translated into performance measures that are used for both day-to-day and strategic management. In the case of asset management, measures would reflect the desired condition or health of physical assets such as pavements and bridge and their needed level of service to meet mobility, safety, environmental and economic objectives. Broader performance management measures might include travel time and delay, fatalities and serious injuries, as well as measure of agency performance such as on-time and on-budget project delivery.

- **Forecasting Performance and Target Setting** – Decisions on how to allocate resources within and across different types of investments are based on an analysis of how different allocations will impact achievement of policy objectives and performance goals. For some goals, this may include forecasting the likely performance impacts of different strategies and setting performance targets. The limitations posed by realistic funding constraints must be reflected in the range of options and tradeoffs considered. For asset management a key issue is always the mix and timing of the appropriate set of maintenance, preservation, rehabilitation, and reconstruction actions given the available funding and the agencies goals and objectives. For congestion relief the issue might be the right mix of capital expansion and operations strategies to address bottlenecks given the funding available.

- **Resource Allocation Decisions Based on Quality Information** – The merits of different options with respect to an agency’s policy goals are evaluated using credible and current data. In the case of asset management, decision support tools, such as bridge and pavement management systems, are used to track system conditions and forecast performance in the future. For some other performance areas such as congestion relief and system reliability, data and tools are also available to evaluate likely performance results. However, for many aspects of performance there are gaps in both the data and the tools available.

- **Measuring, Evaluating and Reporting Performance Results** – The actual performance impact of programs and projects are tracked over time and provide the basis for evaluating the most effective strategies to achieve desired goals. Recognizing realistic timeframes for observing performance results and understanding that these timeframes will vary by performance area is important. For example, for many key performance measures supporting asset management, changes in system performance will only be observable over a number of years. For some aspects of system operations or agency performance, changes can be tracked on a monthly or even daily basis.

The original AASHTO Asset Management Guide \(^1\) recognized that these core principles apply to all aspects of the transportation system. However, some agencies use the term “asset management” to refer to the application of performance management principles to the long-term cost-effective maintenance, preservation, rehabilitation, and reconstruction of the physical assets. Adopting this definition and focus for asset management and using the term “performance management” to refer to the broader application of performance management principles to all aspects of the system, including those covered by a good asset management program, helps to clarify the relationship between the two concepts.
3 STRATEGIC RESOURCE ALLOCATION PROCESS

Understanding the strategic resource allocation process that agencies use to evaluate performance tradeoffs across all goal areas helps to clarify the two concepts of performance management and asset management. Figure 2 shows how TAM principles and tools might influence the strategic resource allocation process, within a comprehensive performance management framework, not just for the physical assets, but also other aspects of policy goals and objectives (The performance areas shown are illustrative and may vary from agency to agency to some extent). The greener the shading, the more TAM principles and tools can be used to influence those decisions. Figure 2 also shows how TAM fits within the performance management framework.

While performance management principles apply to all the elements of this process, asset management refers to the application of these principles to the management of physical assets at a minimum, and highlights its potential role to influence other decisions in varying degrees. This suggested way of looking at the relationship between asset management and performance management is not meant to imply that one is more important than the other. Both are essential in a well-managed transportation agency and program. It is hard to imagine a comprehensive performance management strategy being very effective unless it includes a strong asset management component. Delivering on any transportation system performance goal will require effective management of the physical assets needed to deliver that performance. These physical assets extend beyond bridges and pavement and include, for example, the facilities, equipment, and roadside features that support safety, traffic operations, and traveler information. These assets, as mentioned earlier, include lighting, signing, traffic signals, guard rails, median barriers, drainage, traffic management centers, incident response equipment and other facilities and equipment needed to manage, maintain and operate the system.
4 ASSET MANAGEMENT AND HIGHWAY AUTHORIZATION (MAP-21)

The most recent highway authorization in the US, “Moving Ahead for Progress in the 21st Century (MAP-21)”[^2] mandated the development of a transportation asset management plan for pavements and bridges on the national highway system (NHS) by state departments of transportation (DOTs). State asset management plans must include strategies leading to a program of projects that would make progress toward achievement of the State targets for asset condition and performance of the NHS. The development and implementation of an asset management plan is an important part of the overall Moving Ahead for Progress in the 21st Century framework for enhancing the management and performance of transportation highway infrastructure funded through the Federal-aid highway program.

States must address pavements and bridges but are encouraged to include all infrastructure assets within the highway right-of-way in their risk-based asset management plan. (Also can include roads other than on the NHS.) A State asset management plan shall, as a minimum, be in a form that the Secretary determines to be appropriate and include:

- A summary listing of the pavement and bridge assets on the National Highway System in the State, including a description of the condition of those assets;
- Asset management objectives and measures;
- Performance gap identification,
- Lifecycle cost and risk management analysis,
- A financial plan, and
- Investment strategies

5 PERFORMANCE MANAGEMENT AND HIGHWAY AUTHORIZATION (MAP-21)

A key feature of MAP-21 is the establishment of a performance- and outcome-based program. The objective of this performance- and outcome-based program is for States to invest resources in projects that collectively will make progress toward the achievement of the national goals.

“Performance management will transform the Federal-aid highway program and provide a means to the most efficient investment of Federal transportation funds by refocusing on national transportation goals, increasing the accountability and transparency of the Federal-aid highway program, and improving project decision-making through the development of national performance goals”.[^2]

**National performance goals**

<table>
<thead>
<tr>
<th>Goal area</th>
<th>National goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>To achieve a significant reduction in traffic fatalities and serious injuries on all public roads</td>
</tr>
<tr>
<td>Infrastructure condition</td>
<td>To maintain the highway infrastructure asset system in a state of good repair</td>
</tr>
<tr>
<td>Congestion reduction</td>
<td>To achieve a significant reduction in congestion on the National Highway System</td>
</tr>
<tr>
<td>System reliability</td>
<td>To improve the efficiency of the surface transportation system</td>
</tr>
<tr>
<td>Freight movement and economic vitality</td>
<td>To improve the national freight network, strengthen the ability of rural communities to access national and international trade markets, and support regional economic development</td>
</tr>
<tr>
<td>Environmental sustainability</td>
<td>To enhance the performance of the transportation system while protecting and enhancing the natural environment</td>
</tr>
<tr>
<td>Reduced project delivery delays</td>
<td>To reduce project costs, promote jobs and the economy, and expedite the movement of people and goods by accelerating project completion through eliminating delays in the project development and delivery process, including reducing regulatory burdens and improving agencies’ work practices</td>
</tr>
</tbody>
</table>
6 NEXT STEPS

There are a few issues that have been raised as concerns in the asset management community that should not get lost as attention is given to the broader application of performance management approaches. These concerns include:

- Asset management is an absolutely critical application of performance-based management and decision-making. The bulk of most agencies’ resources are spent in managing and preserving the transportation infrastructure, and effective use of these resources is essential not only for the preservation and performance of these assets but to minimize the funds needed to achieve objectives in this area given the level of funding available.

- An effective asset management strategy must be long term. The focus is not worst-first but least life-cycle cost to achieve facility condition targets over the long term where the desired condition levels and appropriate strategies must reflect the funding available. However, the need for asset management to have a long-term focus is not in conflict with a broader application of performance management principles. A broader application of performance management has to distinguish where short- versus long-term performance goals are the appropriate objective. For the physical preservation of assets the focus should be on the long term even where asset management is part of a broader application of performance management principles. In contrast, some system operational performance goals may be short-term oriented (real time system management as an example).

- Performance measures used to make asset management decisions at the state and local level must be consistent with the long-term focus needed to maintain facilities in the desired condition for a sustainable transportation system. Part of the concern about asset management needing a long-term focus may be due to the fact that IRI is the only pavement condition indicator available nationwide on a consistent basis. As a result, IRI has been suggested as one of the measures for an initial national performance measure reporting effort. However, surface roughness alone, which IRI measures, is not a sound basis for allocating resources to pavements and there is broad agreement that a comparable pavement structural condition measure also is needed. AASHTO and FHWA have begun work to define more robust pavement and bridge health measures that could be used on a consistent basis nationwide. AASHTO and FHWA are also working together to develop appropriate national performance measures for other aspects of system performance.

All states have asset management programs focusing on pavements and bridges. However, a comprehensive asset management strategy should include all the physical assets that support the full set of performance goals, including safety, system operations, traveler information, environmental stewardship, and agency operations. These assets include signing, lighting, guard rail and median barriers, rest areas, traffic signals, traffic operations centers and other buildings, equipment, and facilities will require that all key physical facilities be included.

In addition to addressing these issues, a number of recent asset management and performance management workshops, peer reviews, and conferences have identified a number of other important action items for the asset management community. All of these issues have been identified in the new Asset Management Strategic Plan (2011-2015) and include:

- Communicate the benefits of applying transportation asset management throughout the life cycle of all assets to policy and technical decision-makers, elected officials, and other stakeholders.
- Support the development of a performance-based Federal program based on sound transportation asset management and performance management principles.
- Continue to define and communicate both the common features and the differences between transportation asset management and broader performance management.
7 CONCLUSION

The basic principles of asset management and performance management are the same and the two concepts are not in conflict. This discussion paper suggests that the term asset management be used to describe a performance-based approach for managing transportation system physical assets. The term performance management can then be used to describe the application of the same basic principles used in asset management to the broader set of performance objectives related to system operations/reliability, safety, congestion relief, freight mobility, environment, etc., as well as to aspects of a transportation organization itself such as project and program delivery.

8 REFERENCES


Why Congestion Charging?
Value proposition and study from different angles

Luis Miranda
Purpose of Presentation

• Outline essential aspects of the legal framework and the minimum infrastructure needed

• Existing solutions for Congestion Charging

• High-level description of technology overview

• Business Case

• Key lessons
## Agenda

<table>
<thead>
<tr>
<th>About Q-Free</th>
</tr>
</thead>
<tbody>
<tr>
<td>Why Congestion Charging?</td>
</tr>
<tr>
<td>Value Proposition</td>
</tr>
<tr>
<td>Prerequisites</td>
</tr>
<tr>
<td>Solution Description</td>
</tr>
<tr>
<td>Business Case</td>
</tr>
<tr>
<td>Summary – Key lessons</td>
</tr>
</tbody>
</table>

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265
A pioneer in Road User Charging

- Leading global supplier with unique portfolio of solutions for electronic toll collection and Traffic Management
- Represented in 18 countries, headquartered in Trondheim, Norway, ~400 employees
- Listed on the Oslo Stock Exchange (QFR) – market capitalization of ~ NOK 800 million

Our vision is to be the globally preferred partner within Intelligent Transport Systems, and provide worldwide leadership in Road User Charging and Advanced Transportation Management
Wide geographic reach and key references
Road tolling to traffic management

**RUC**
Road User Charging
- Electronic Fee Collection
- Congestion Charging
- Truck Tolling
- Image Handling Systems
- Electronic Registration Identification

**ATMS**
Advanced Transportation Management Systems
- Parking Management Systems
- Urban Traffic Management
- Infomobility
- Inter-Urban Management
- Cooperative ITS

**MS**
Managed Services
- Commercialise new recurring revenue concepts
- Strengthen revenue base and profitability
- Increase financial predictability
Agenda

- About Q-Free
- Why Congestion Charging?
- Value Proposition
- Prerequisites
- Solution Description
- Business Case
- Summary – Key lessons
Congestion Charging is an electronic fee collection system designed for the purpose of reducing traffic congestion, by motivating users to use public transport services, reduce their number of journeys or to avoid peak traffic periods.
Global Volume of Road Transport is Expected to Grow 111% from 2000-30

Market Drivers

- Rising level of congestion
- Environmental concerns to improve air quality & noise pollution
- PPP to reduce budgetary constraints
- Increased public acceptance to reduce waiting times
- Road safety increase the need to managing congestion

Why Congestion Charging

Transport Activity Growth, 1990-2030 (2014)*

*Source: EU Energy & transport trends 2030
The Objective is to Reduce Traffic and/or Move the Traffic during Rush Hours to Other Times

- Considerable fee for undesirable public behavior
- Smaller fee for alternative public behavior
- No fee for optimal public behavior
- Reward for desirable behavior can be offered as option
### Congestion Charging Solutions Exist Worldwide

<table>
<thead>
<tr>
<th>Country</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sweden</strong></td>
<td>• Congestion Charging in Stockholm and Gothenburg to reduce traffic peaks</td>
</tr>
<tr>
<td></td>
<td>• Q-Free has delivered the complete roadside package and ALPR (Automatic License Plate Recognition) software</td>
</tr>
<tr>
<td><strong>Italy</strong></td>
<td>• Introduced Video Tolling in Milan for Congestion Charging purpose</td>
</tr>
<tr>
<td></td>
<td>• End-users buy “Eco-passes” to get access to the city</td>
</tr>
<tr>
<td><strong>Singapore</strong></td>
<td>• Electronic road toll collection system for purposes of Congestion Charging</td>
</tr>
<tr>
<td><strong>Great Britain</strong></td>
<td>• Congestion Charging in London by pre-payment before access to the city centre zone</td>
</tr>
<tr>
<td><strong>Norway</strong></td>
<td>• System to finance road infrastructure, with less congestion in the city centre as one of the effects</td>
</tr>
<tr>
<td><strong>Australia</strong></td>
<td>• Q-Free has implemented Time of day Tolling for Sydney Harbour Bridge and Tunnel</td>
</tr>
</tbody>
</table>
Several Stakeholders Benefit from an Effective Congestion Charging System

Authorities

- Reduce congestion and manage traffic flow
- Reduce traffic
  - Curb pollution
  - Motivate for use of public transport
  - Improve road safety
- Stimulate increased use of Intelligent Traffic Solutions (ITS)
- Finance maintenance and construction of road systems
  - ‘User pays’ concept
Several Stakeholders Benefit from an Effective Congestion Charging System

**Toll Chargers (Operators)**
- Low investment costs
- Efficient operation model
- Education and advisory through deployment and implementation
- Interoperability according to international standards
- Capacity expansion without large additional infrastructure investments

**End-Users**
- Reduced travel time
- No need for cash and receipts with automatic payments
- For companies; all vehicles in one invoice
- Enable drivers to make toll payments at high speed without stopping
- Positive end-user experience, by 100% reliable transaction handling.
Agenda

- About Q-Free
- Why Congestion Charging?
- Value Proposition
- Prerequisites
- Solution Description
- Business Case
- Summary – Key lessons
## Basic Prerequisites

### Prerequisites

<table>
<thead>
<tr>
<th>Introduction of a Congestion Charging system requires a matching infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Political Motivation</strong></td>
</tr>
<tr>
<td>• The introduction of a Congestion Charging system should be supported by the political environment as well as the owner of the business case.</td>
</tr>
<tr>
<td><strong>Legal Framework</strong></td>
</tr>
<tr>
<td>• The legal framework must clearly define a liability for payment of toll fees.</td>
</tr>
<tr>
<td>• The toll service provider must have access to means to enforce payment</td>
</tr>
<tr>
<td>• Where applicable, standards must be adhered to.</td>
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<tr>
<td><strong>Protection of Privacy</strong></td>
</tr>
<tr>
<td>• The solution must be designed so that it complies with laws and regulation related to privacy.</td>
</tr>
<tr>
<td><strong>Governmental Control</strong></td>
</tr>
<tr>
<td>• Authorities must supervise the system. This is applicable for all Electronic Toll Collection systems.</td>
</tr>
<tr>
<td><strong>Contractual Liability</strong></td>
</tr>
<tr>
<td>• The basis for determining proof of passage must be found. Electronic transaction record? Video image?</td>
</tr>
<tr>
<td>• The issuer of the means of payment must be fully liable for compensating claims from different service providers.</td>
</tr>
</tbody>
</table>
What Vehicles should be Applicable for Tolls?

### Charging
- Type of charging dictates the need for roadside equipment and vehicle OBUs.
- Special rules, e.g. max fee, free passing, toll liability
- Pre- and/or post payment is possible
- Pay per passing/per day/max payment etc.
- Based on Time/Distance/Places/Zones and/or vehicle type

### Classification
- Classification gives opportunity to distinguish between different types of vehicles
- The class of a passing vehicle can be detected by roadside detectors
- Back Office classification can distinguish between vehicles based on information from vehicle registry (e.g. maximum allowed passengers, engine power etc.)
- Examples of vehicle characteristics:
  - Heavy vehicles (maximum allowed weight of more than 3500kg)
  - Long vehicles (more than 3 axles/length more than 12m etc)
  - Addition of trailer

### Foreign Vehicles
- If foreign vehicles are subject to tolls, the payer must be identified by:
  - Direct agreements with the authorities responsible for vehicle registries in neighbor countries
  - Use of empowered 3rd party suppliers
- International projects are working on a standard on how to exchange passage data and connected payer information between countries
- For some tolling schemes where all foreign vehicles have to pay, they need a pre-paid account, and order an OBU at the border, or in advance
Quality of License Plates and Access to Vehicle Registry Affects the Operational Model

**Vehicle Registry**
- Access to the National Vehicle register is an advantage → makes automatic enforcement possible
- Different companies can support access to foreign vehicle register, Q-Free has close cooperation with companies and can deliver solutions for this
- Vehicle register must be kept up to date at all times

**License Plate**
- Are the license plates unique and of good quality?
- License plates must be trusted, i.e. the fraud level must be minimized
- Electronic identification using an OBU may be necessary or mandatory in countries where number plate quality is unsuitable for automatic reading
Charging, Foreign Vehicles and Classification

Decisions to be made:

• Should foreign vehicles be applicable for toll?
  o Pre-payment on the border or on the web

• Should larger vehicles pay more than smaller`?
  o Possible with measurement of axels, length and height
  o Which vehicles will drive for free (motor cycles, electric cars, buses, emergency cars etc.)

– Should fees be flat or flexible?
  o E.g. higher fees during peak hours
  o Flexible fees has a greater impact on exploiting road capacity

– Pay per passing or per day?

– Should charging be pre-payment (user initiative) or post-payment (service provider initiative)?
  o Post-payment puts higher demands on technology to register all passing vehicles (if pay per passing)
  o Pre-payment are easiest combined with flat fees in a congestion charging system
Agenda

- About Q-Free
- Why Congestion Charging?
- Value Proposition
- Prerequisites
- Solution Description
- Business Case
- Summary – Key lessons
Basic Elements of a Congestion Charging System

**Solution Description**

**Passage Collection System**
- Detection and Data Collection
  - Identification
  - OR
  - DSRC
  - Video
  - Classification
  - Time stamp
  - DSRC mismatch
  - Enforcement

**Operational Back-Office**
- Automatic Execution
  - ALPR
  - Toll Calculation
    - Based on time/place/size etc.
  - Transaction Data
    - Sent to Commercial Back-Office for charging

**Commercial Back-Office**
- Semi-Automatic Execution
  - Assets & Facility Management
  - Invoicing & Financials
  - Customer Relationship Management
  - Administration

**Users and Externals**
- Service and Support
  - Equipment Monitoring etc.

- Users
  - End-Users
  - Customer Service
  - Authorities
  - Enforcement Operators

- Externals
  - Banks
  - Vehicle Registry
  - Clearing
  - Logistics
In Congestion Charging schemes there are 2 main alternatives for Detection and Data Collection for Positioning and Identification; DSRC and Video with ALPR.

The Passage Collection System is the part of the system responsible of securely measuring toll object usage and provide charge data to the toll calculation module in the Operational Back Office for processing.

Detection and Data Collection
- Identification
- DSRC
- Video
- Classification
- Time stamp
- DSRC mismatch

In Congestion Charging schemes there are 2 main alternatives for Detection and Data Collection for Positioning and Identification; DSRC and Video with ALPR.

DSRC: Dedicated Short-Range Communications
ALPR: Automatic License Plate Recognition
Roadside – Time stamp for Price Calculation

**Flat Fee**
- Same fee 24/7
- No need for data about time and location for fee calculation

**Flexible Fee**
- Fee calculated by time of the day, day of the week and/or place/zone
- E.g. During peak hours there will be higher fees, and inner city zone can have higher fees than outer city zone
Roadside Enforcement

Enforcement Equipment mounted on road side:

- Surveillance/context Camera
  - Vehicle class verification

- ALPR Camera
  - Identification and proof of passage

- Laser Scanner
  - Detection and classification

- DSRC Antenna
  - Receiving data from the OBUs

- Transceiver and processor
  - Initiates OBU wake up

- Multi Lane Controller
  - Monitoring, verification, processing

The enforcement system on Roadside verifies the vehicle On Board Unit and classification information etc.

A missing OBU or classification mismatch results in a photographic evidence for the passage being sent to the Back Office.

Automatic Number Plate Recognition
Automatic and Manual Handling of Enforcement Cases

Q-FREE
Operational Back Office Functions

Automatic Number Plate Recognition (ALPR)
• Incoming pictures of passages from roadside are translated automatically by ALPR Software
• If a vehicle cannot be identified, it will be handled by MCR (Manual Character Recognition)

Toll Calculation
• Toll is calculated from given rules in the system
• Rating based on Time/Distance/Place/Zone/Class
• Charging data is attached to OBU ID or Licence plate number

Transaction Data
• The calculated toll is attached to the identified vehicle and a transaction is generated for accounts handling
• Transaction data sent to Commercial Back Office for invoicing
• Enforcement cases sent to Commercial Back Office for handling

Other functions in the Operational Back Office:

Monitoring
• The Monitoring Centre is responsible for monitoring the equipment status at the sites
• Q-Free provides standard software monitoring tool for monitoring of Control Points
• Required hardware consist of standard PCs

Reporting & Statistics
• Generation of different reports to authorities and other stakeholders
Commercial Back Office Functions

Assets & Facility Management
- Assets management: Support distribution of On Board Units, logistics, etc.
- Facility management: Supporting tool for the logical layout of the toll plazas (equipment, lanes, etc)

Invoicing & Financials
- Invoicing to account according to transaction data and enforcement data
- Reminders
- Collection of Debts (can be outsourced)

Customer Relationship Management
- CRM system with customer data and automatic customer services
- Costumer handling, end-users support, keeping track of customer and accounts database, complaints handling, etc.

Administration
- System Configuration Parameters
- User Access and Audit
- Data Archive/Restore Management
- Administration of price file, portals and On Board Units
User Interfaces

Point of Sales
- Point of Sales is the location where the user can acquire an On Board Unit and fill in the contract details.
- The user can also refill his pre-paid account
- Authorized personnel will use the system to lookup and maintenance of customer/OBU data and handling over OBUs

Customer Service
- Call Centre operators will handle enquiries from road users, look up complaints and comments
- Can be automated and/or manual

Enforcement Operators
- The Enforcement Agent inspects enforcement cases reported from the system
- By examination of collected video images and user declared vehicle characteristics, a decision is made whether they are compliant or if the passage is an offence
- Enforcement Operators in Mobile Enforcement Vehicles will stop suspected toll offenders, resolve toll offences, issue penalties and collect unpaid toll

Authorities
- The authority is often the legal owner of the system
- The authority will need different sets of reports
External Interfaces

Banks
- Banks are responsible for transferring of funds and issuing of receipts
- They provide the appropriate account statements in electric form, hold users’ financial credit/debit accounts, and ensure services like autogiro, web and credit cards
- Each Toll Company must enter into an agreement with the Bank for the use of Their Payment Solution

Vehicle Registry
- The Public Vehicle Register is used to identify the owner of the vehicle, to check registered vehicle characteristics and as support to enforcement incident processing

Clearing
- Clearing of foreign vehicles and clearing between different operators. This includes clearing of transactions from vehicles not having a contract with the system.

Logistics
- Logistics will manage On Board Units, information materials and other accessories, and maintain appropriate stock levels at contact and distribution points

Print Shop
- Print shop will handle mass distribution of customer correspondence such as invoices and other documents
Agenda

- About Q-Free
- Why Congestion Charging?
- Value Proposition
- Prerequisites
- Solution Description
- Business Case
- Summary – Key lessons
Congestion Charging only Requires Conventional Costs

Cost Drivers CAPEX:
- Toll Plazas
  - Dependent on number of lanes
- On Board Units (if not video based system)
  - Handling, storage, distribution, etc.
- Same infrastructure on road side as conventional systems

Cost Drivers OPEX:
- Legal requirements pertaining to enforcement
- Tariff models (user groups, rebates, exemptions, casual users)
- Required response time case handling
- Exempt handling

Size of organization that will operate the system

Example of OPEX Target: < 10 % of revenues
DSRC versus ALPR

- DSRC & ALPR yields lowest Total Cost of Ownership
- Indecisive, depends on local factors such as tag distribution costs
- ALPR yields lowest Total Cost of Ownership

Tag Unit cost (€)
(with battery lifetime of 5-7 years)

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<th>ALPR read rate (%)</th>
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Example:
If each tag, with a battery lifetime requirement of 5-7 years, costs 10 EUR, and the license plate quality enables 95 % read rate, ALPR yields lowest Total Cost of Ownership (green)
This example illustrates the revenue when operating 365 days a year, at 1 € for each passing.
Agenda

- Why Congestion Charging
- Value Proposition
- Prerequisites
- Solution Description
- Business Case
- Why Q-Free
- Summary – Key lessons
Summary – Lessons learned

Key lessons for implementing congestion charging

- Recruit a committed political champion and clear governance
- Establish business case and adequate approved budget
- Extensive public consultation
- Ensure adequate public transport alternatives
- Use proven technology
- Ensure a successful debut and plan adequate contingencies
- Strong project and contract management
- Open communication and information of revenue collected and how it is used to maintain and improve infrastructure while offering more alternatives to the users
Q-FREE

Thank you!

For any additional information:

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Leading the way in road user charging and advanced transportation management
ABSTRACT:
The deployment process of Cooperative Intelligent Transport Systems in Europe has reached its first milestone: Day One, 2015. Although the feasibility and benefits of C-ITS have been largely demonstrated in the past decades, there is still a gap between this category of implementations and the large-scale deployment: real-life implementations should be effective, geographically-continuous, interoperable and demonstrate a high degree of maturity. This paper aims to answer this question from the SWARCO perspective. SWARCO, with a long experience in ITS systems and TMCs design, has extended its OMNIA platform in line with actual trends regarding C-ITS applications and concepts. With particular reference to issues related to large-scale implementations of C-ITS, this document will provide some insights about the SWARCO approach and best practices, which are meant to support these upcoming challenges.
Introduction
More or less a decade has passed since initial cooperative systems ideas were discussed and R&D started for developing technology, standards and executing large field deployment tests. Still consumers and even experts cannot see C2X in market products. Why are there no offers? Considering all the development still active - is technology really ready? Looking at the state of the art in a few examples shall shed light on this question.

Tackling the challenge
The basis for the pan-European deployment of cooperative ITS is already in place. The Cooperative ITS technology has been developed within RTD (Research and Technology Development) projects and is evaluated in FOTs (Field Operational Tests). This paragraph is naming some of the most important of these initiatives tackling the challenge of C-ITS large-scale deployment, where the preparation and the gradual deployment of the new technology are taking place in close exchange with the partners on a European level.

ECo-AT (European Corridor – Austrian Testbed for Cooperative Systems) is the Austrian project which objective is to create harmonised and standardised cooperative ITS applications jointly with partners in Germany and the Netherlands. The project is led by the Austrian motorway operator ASFINAG and the consortium consists of Kapsch TrafficCom AG, Siemens AG Österreich, IPTE – Schalk & Schalk OG, SWARCO AG, High Tech Marketing, Volvo Technology AB, FTW, ITS Vienna Region, and BASt (Bundesanstalt für Straßenwesen). SWARCO contributes in the specification of the overall system and provides SW and/or HW components for the whole infrastructure-chain of information from the TCC (Traffic control centre) interface to C-ITS-S (Central ITS Station) down to the R-ITS-S (Roadside ITS Station) which could be mobile on trailers or fixed. C-ITS services will run operationally in Eco-AT in a so called “Living Lab”.

The Compass4D three-year EU co-funded project is deploying three services in the cities of Verona, Bordeaux, Vigo, Newcastle, Thessaloniki, Helmond and Copenhagen in order to prove the concrete benefits of cooperative systems for citizens, city administrations and companies. Compass4D has started piloting its services (meant to last for one year) on 334 vehicles, including buses, taxis, emergency vehicles and private cars, reaching more than 550 users. In Compass4D, SWARCO is supporting the Pilot Sites of Verona and Thessaloniki by providing the EEIS (Energy Efficiency Service) for circa 200 intersections and the RHW (Road Hazard Warning) service for the whole city of Verona and the Thessaloniki ring road.

The TEAM project develops new collaborative transport solutions through combining automotive cloud and distributed computing technologies with novel telecommunication technologies where DSRC and cellular-based communications are equally used to bring relevant dynamic information to all road participants. Within this context, travelers will benefit from 11 collaborating applications providing real time recommendations to balance individual and city mobility needs. TEAM is moving from the paradigm of “cooperative” to the one of “collaborative” ITS by realizing applications in which users collaborate within the community, in order to reach a common goal (e.g. area-wide traffic optimization).

C-ITS generic architecture
In order to support the deployment of all services mentioned in the previous section, there was the need of developing an integrated platform capable of fusing all the information coming from different sources and apply business rules that provide the required output for traffic management. Errore. L’origine riferimento non è stata trovata. provides a functional architecture of the OMNIA platform, which is able to collect and integrate a large variety of existing systems and infrastructure equipment into a single user interface. This platform would then apply cross-system business logic to provide the necessary cooperative functions required for the services mentioned before. C-ITS services can leverage on 2 main communication technologies such as UMTS/LTE or ETSI ITS G5. Both technologies can work together and complement each other when needed.
Within this functional architecture, there are three “channels” for the interaction between the TMC and the field:

- OEM: in this case, the traffic management centre sends all the relevant data to a private back-end which forwards the information to selected vehicles. mobile communication is generally used in this configuration.
- RSU (roadside units): in this case, the rsu use the etsi its g5 standard (based onieee 802.11p) to deliver the information to equipped vehicles. they act as a bridge between the traffic management centre and the vehicles, and since they are limited in computational resources, most of the task is to coordinate the services and guarantee the continuity of the service done in the centre.
- Public: this back-end plays the same role as the one of the oem with the difference that this is open to the public i.e. any person equipped with an app able to interact with the service will connect to this back-end. mobile communication is also used is this configuration.

**Best practices – an overview**

**RWW - Road Works Warning**
The use case RWW informs drivers of road works, its parameters and associated obstruction (e.g., lane closed) on the route ahead on an in-car device. The purpose is to increase the awareness of drivers and to inform of potentially dangerous situations. The added value of the cooperative approach is increased accuracy of the road works information in time and location for the benefit of the end user. The use case is presented from a general perspective without paying attention to the implementation details. The reason is that different guidelines and legacy systems to manage road works are in place in every country. Today’s RWW is realized with low sophisticated safety trailers that just give information on a lane closures and if a drivers shall pass right or left (see Figure 2). Mostly, they are realized with static signs. To support cooperative services, the idea is to enhance the safety trailer with a GNSS unit and a R-ITS-S station.

**Figure 2 – Safety trailer with variable message sign**
In general, two different scenarios are realistic in day 1 applications: safety trailer connected to a C-ITS-S or a standalone safety trailer. The first scenario is presented in Figure 1. However, it has to be considered that the R-ITS-S is moving. The second scenario is limited in the provided information to the driver because only information coming from the safety trailer is available (i.e., time, the position/direction, speed of the trailer and the aspects shown on the sign) for disseminating warning messages.

The challenges are to get the exact location of the safety trailer (i.e., information on the lane the trailer is placed on) and the approach to the trailer (so called “traces”). Data on the exact location may come from national guidelines that specify the layout of road works. Traces could be generated during the transport of the safety trailer to its destination. In Day One, messages are sent using the DENM format. Application specific information is disseminated using the “RWW alacarte container”. In case of scenario 1, information on the closed lanes status, the hard shoulder status and the speed limit can be provided. On the contrary, the standalone safety trailer only sends a message with the “traffic flow rule”: pass trailer to the right or left.

With the advent of more sophisticated trailers using LED based variable message signs further information can be displayed (see Figure 2). Consequently, in-vehicle signage (IVS) has to be used in Day Two applications.

**TLA - Traffic Light Assistant**

TLA, the service described in this paragraph, is able to provide indications related to intersections crossing in order to reduce waiting timings, energy consumptions, the emissions, and at the same time to increase the level of comfort of drivers (either private or public) and of all users of the urban road infrastructure. Even though the driver is the direct beneficiary of this service, it can also be seen as a complementary tool to the strategies of public transport priority, as it provides information to the driver about the optimal speed or time to devote to the bus stop, considering the state of the next set of traffic lights and eventual requests for traffic light priority.

Within the actual implementations, the service is being delivered to the final user through a mobile APP (available for Android and in development phase for iOS), which can be used not only for vehicle drivers but also for bike users, that could benefit from the information generated by the system in order to improve the level of comfort of their journey. Through the TLA service, two main categories of information are being delivered to the user:

- **Green Light Optimal Speed Advisory (GLOSA).** This functionality is proposing to the driver the optimal speed, in compliance with legal speed limitations, in order to cross the intersection without the need to stop in order to wait for green. Whether this is not possible due to the red duration, an optimal speed advice is being delivered in order to improve the vehicle’s duty cycle (i.e. the alternation of acceleration, cruise, costing and braking phases). In synergy with the “green wave” urban traffic control strategies, the vehicle is therefore driven through a more regular and eco-friendly path.

- **Time To Green (TTG).** When it is not possible to identify an optimal speed for the intersection crossing with green light, the system will deliver an information related to the red waiting time, thus reducing the driver’s stress (it is demonstrated that quantified waiting times are perceived as lower respect to the unknown ones) and also reducing the driving micro-dynamics (small movements of vehicles involved in a queue). The cooperative management of start&stop on board systems represents also a potential application of this functionality.
Additional to the information described before related to the traffic lights status, the SWARCO mobile APP is also enhanced with the capability of displaying information related to urban mobility events.

**PVD – Probe Vehicle Data**
In this C-ITS use case, equipped vehicles monitor urban roads and recognize incidents or special events (road closures, work zones, hazards) while driving and provide real-time information to the TMC, which validates the reliability of this information and optimizes the traffic efficiency by applying management and control logics on a broader data set. Such innovative paradigm is based on the information that comes from the vehicle, which can be intended as a moving monitoring sensor, and on proactive distributed traffic management, through I2V communication and information collection from other data sources (e.g. crowd sourcing, mobile devices, potentially data mining from social networks) and existing legacy monitoring system (e.g. inductive loops used for UTC systems operations, Bluetooth sensors, CCTV cameras).
This use case can be to some extent intended as a B2B base for enabling new V2I applications and improving existing TMC features, such as real-time traffic monitoring and forecasting, and traffic demand management. As said, information will be gathered from different sources and this can also provide a kind of helicopter view concerning information and control effects at network level. This can therefore be used as a validation tool aimed at the identification of the impact on mobility of strategic actions such as collective re-routing, parking guidance, or to evaluate the effectiveness of adaptive UTC strategies for green corridors or prioritization schemes aimed at reducing congestion, energy consumption and consequently emissions level.
Recent deployment of a test application of PVD technology is related to the city of Rome. Here data is collected from existing legacy road sensors (inductive loops of the local UTC system UTOPIA) and from a number of mobile sources. These consist of Here Maps users, including smartphone and tablets users, mobile navigators, logistics operators, public transport operators, and postal services operators. The implementation is currently supported by UMTS and LTE technologies, but 802.11p utilisation is under investigation. All the data collected are mashed up and processed in a dedicated TMC installation based on OMNIA, in order to obtain reliable traffic forecasts regarding the status of the network in the short and midterm to define estimated LoS (Level of Service), travel time, saturation ratio and forecasted utilization of the arcs of the road network.

**IVS – In-Vehicle Signage**
In this use case central and roadside systems, again using a combination of cellular and DSRC communications, send messages to approaching vehicles, increasing the likelihood of drivers being aware of potentially dangerous conditions in case a roadside traffic sign is not noticed, or an accident has happened on the road right in front of the vehicle.
The core feature is therefore the representation of the on-board display of the road signs in the path of the vehicle, with particular reference to Variable Message Signs (VMS) and to Variable Speed Limits (VSL) in motorways or in interurban expressways. In this case, this function is also intended to enhance the safety of vehicles and travellers which approach a traffic jam or build the tail end of a traffic jam, caused by an incident or by recurring congestion. This particularly aims at avoiding rear-end collisions that are in most cases caused by traffic jams on highways. With help of V2I-communication, vehicle and personal ITS systems are able to warn the driver even before the traffic jam can be perceived by the driver himself. In this way, the driver is informed in time and can react smoothly and safely. As a side effect, the funnel effect on vehicles’ speed can increase the capacity of the bottleneck and at the same reduce the energy consumption needed for stop&go motion of approaching vehicles. Finally, an extension of this use case is related to rural environment, and more precisely to detecting an upcoming disabled vehicle and warning other/following cars, as well as TMC operator and public intervention forces, that a vehicle is on the road or disabled.

Concerning deployment, at the moment this functionality is presented together with the TLA by means of a mobile application that is connected with OMNIA end-users services and that is able to present on the map and in a separate view the type and distance of the accident related to the on-board signal. Further planned developments are related to the integration of this with standardised DENM services, as well as with 802.11p-based communications.

Conclusions
Deployment of the services mentioned in this paper have shown their capabilities. Benefits to economic and environment as well as to the travellers’ experience of a good journey are clear. One of the promising next steps will be to take this scenario to a broader number of cities and regions, also paying attention to relevant C-ITS initiatives such as the European Corridor (Rotterdam-Vienna) and related projects, which are nowadays performing pre-deployment across Europe (e.g. Compass4d) or studying innovative applications based on cooperative technology (e.g. TEAM). The use of these new “sensors” gives cities the possibility to expand their situation knowledge. Giving back better and new data widens the spectrum for effective actions to improve the traffic situation for the benefit of its inhabitants and to contribute to a positive traveller experience. Thus the industry is ready with initially attractive developments. Now the market development and the cooperative actions taken between stakeholders is the challenge to make it happen.

Acknowledgements
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PAPER TITLE: Intelligent Streetlight Management for Interchanges and Parking Areas in Extra-Urban Environment

TRACK: D.4 Case Studies in ITS Deployment

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KEYWORDS: intelligent streetlight management, wireless sensor networks, road infrastructure monitoring, LED luminaires

ABSTRACT:
An analysis of lighting system costs over 20 years, performed within a study on practical matters of roadway lighting systems in Europe, shows that in certain cases electric energy reaches two thirds of the total system cost. Furthermore, in some countries administrations limit the amount of annual energy consumption (KWh/year) for lighting. The common approach in order to tackle this issue applies the dimming of the lighting during late night hours.

This paper proposes an enhanced solution to the management of public lighting in extra-urban environment (e.g. interchanges and parking areas) that implies the installation of resource efficient LED based luminaries together with the exploitation of a traffic adaptive streetlight control. The implementation of such a control mechanism requires real-time sensor data in order to dynamically adjust the luminance intensity of the streetlights in compliance to the current traffic situation. The proposed detection system is based on a low-power, low-maintenance and low-cost WSN designed for road infrastructure monitoring, featuring multiple functionalities.
Intelligent Streetlight Management for Interchanges and Parking Areas in Extra Urban Environment

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INTRODUCTION

Street lighting in urban areas consumes today a very high amount of energy. Nowadays, in most of the cases, the streetlights system is driven by a fixed plan programming: they are simply switched off and on according to inputs of day and night sensors. Energy efficiency of lighting installations for smart cities can be significantly increased as requested by European Commission (EC) directives by deploying LED (Light Emitting Diode) based lights. In addition, sometimes level of luminosity is reduced on a time based manner during the on-time.

An analysis of lighting system costs over 20 years, performed within a study on practical matters of roadway lighting systems in Europe, shows that in certain cases electric energy reaches two thirds of the total system cost. Furthermore, in some countries administrations limit the amount of annual energy consumption (KWh/year) for lighting. The common approach in order to tackle this issue applies the dimming of the lighting during late night hours.

Therefore, it can be stated that smart street lighting represents one obvious starting point in the deployment of smart cities and smart roads. In urban areas, statistics show that aging street lights can eat up to 40% of a city’s overall energy budget. There is a clear business case where implementing networked LEDs can drop this overall number by two-thirds, with the additional benefit of lowering operational costs, extending lighting network life spans, creating a safer environment for citizens, and establishing a “canopy network” under which other future services can be delivered. Furthermore, nowadays, LED technology is being implemented together with traffic management technologies, in order to maximize the efficiency of resources. (Hughes, 2014)

A next step after introducing LED luminaires, has been the integration of intelligent functionality in today’s streetlights. One of the first ideas was to add a communication module to each streetlight making it possible to control and monitor each luminary individually from a central station via wireless or wired communication. The following step is related to the approach of a combined lighting and traffic management system to realize traffic adapted intelligent management of streetlights by exploiting the dimming capabilities of LED streetlights. (Novak, 2013)

This paper describes a system that combines LED technology with WSN (Wireless Sensor Network) -based road traffic monitoring technology that aims to represent a challenging solution for intelligent streetlight management for interchanges and parking areas in extra urban environment. A first section of the document contains a system architecture overview while a second part is focusing on a real life implementation of the solution and the results obtained from a three-months installation in a real-life environment within COSMO EC-funded project.

SYSTEM ARCHITECTURE

The application object of this paper is related to the management of public lightning system according to the traffic conditions in interchanges and parking areas in extra urban environment. This section is describing the two major components of the system: the lighting system based on LED luminaires and the WSN-based traffic monitoring system.

The generic architecture of such an adaptive control scenario has been already presented in previous works (Novak, 2014) and involves the use of smart sensors for traffic monitoring that allow the assessment of the emitted light in function of the traffic condition, as shown in the figure below: based on the sensor data, the situation is assessed in the streetlight management. Moreover, control commands can be derived and sent to designated streetlights. Following this concept, the road is logically segmented meaning that the luminance intensity of all luminaries in a segment is altered in the same way.
The streetlights proposed for the implementation of the system are called FUTURLUX. It is an innovative approach of using LEDs in street lighting.

The innovative features relevant for the type of application in described in this paper are:

- up to 80% energy saving compared to other lighting techniques
- optimized thermal management for lowest LED degradation
- excellent longitudinal uniformity of luminance
- 1, 2, 4 or 6 LED modules for various levels of luminosity

The traffic monitoring system is based on a system called RED-WINE (Albertengo, 2013), a multi-sensor system that aims to provide a solution for generating automatically safety warnings at ‘black spots’ by using traffic-related data acquired on the road network. The system features three main characteristics - (i) low power, (ii) low cost and (iii) low maintenance - combination that represents the strength of RED-WINE respect to other existing solutions (e.g. magnetometers based systems).

The traffic monitoring system is based on a system called RED-WINE (Albertengo, 2013), a multi-sensor system that aims to provide a solution for generating automatically safety warnings at ‘black spots’ by using traffic-related data acquired on the road network. The system features three main characteristics - (i) low power, (ii) low cost and (iii) low maintenance - combination that represents the strength of RED-WINE respect to other existing solutions (e.g. magnetometers based systems).

The system, made up of sets of nodes installed on the roadside is able to provide an integrated solution for road infrastructure monitoring with following features: crash and barrier tilt detection, traffic status detection (occupancy variations), monitoring of environmental parameters (i.e. ice warnings), WWD detection, indoor localization on road axis (adapted for tunnels or bridges) and colour-coded signalling (luminous wave and on/off flash). The node (called GRAPE), composed by an acquisition module, a communication module and a power-supply module, is the RED-WINE core element.

An advanced wireless communication protocol in 2.4GHz ISM band has been designed and implemented in order to permit communication among a large number of nodes, taking advantage of the linear topology of the network, typical for extra-urban roadside applications. The wireless connectivity reduces the cost of installation and maintenance with respect to the existing monitoring technologies and, at the same time, offers a much greater flexibility of deployment, providing a comprehensive and high-resolution sampling of traffic variables, that permit, on centre side, to reconstruct the spatial–temporal evolution of traffic flows and locate any detected anomaly along the road.

In order to provide the desired performances for the intelligent lighting application, the WSN system needs to be installed in order to monitor the traffic in the cross road in the green circle and to manage the public lighting system in that area. The application requires the integration of several wireless sensors in the system, in order to obtain a clear view of the traffic conditions, rapid detection of vehicle passage and consequently quick responses of the lighting system.

The sensors' system architecture is based on the deployment of wireless sensor nodes in the area of interest, forming the WSN in the observation field. Sensors and their MA are connected with radio interfaces to the deployed wireless nodes; parameters detected will be conveyed via the established wireless network to the WSN central sink (the gateway, GTW) for further processing. The gateway provides elaborated data to the traffic control centre regarding network parameters and traffic data.

The various modules that compose RED-WINE system are described:
WSN nodes
WSN gateway: The WSN gateway is an industrial PC provided with a radio gateway. The main functions of the gateway is to aggregate information coming from the nodes and forward it to the WSN centre, and implement the watch-dog procedure for the whole network.
WSN server: WSN server is hosted in the control centre room. It’s role is to receive information from various gateways on field, store all data into database and forward it to the appropriate module according to the specific application for further elaboration and visualization.

In this particular configuration, the WSN gateway has some extra functions:

- Driving the lightning system: electrical connection to the lamps networks allows their driving. It is considered initial and default configuration a reduced intensity of light. When a vehicle passage is being detected, the gateway drives the appropriate pin at 220V that deactivates the dimming mode of the lamps, and the intensity of the light reaches 100%. A timeout period has been calculated starting from the last received passage, in function of a minimum speed. For all three directions switching times of the lamps are calculated in order to ensure safe timings between lights reaching the 100% of light intensity and the actual passage of the vehicle. After the timeout period, the lightning system returns into the dimming state.
- Communicate the passage information to the other gateways in the system: an internal communication protocol has been developed in order to permit the communication of information from one gateway to the others

All data is being sent by the gateways at the control centre and is being stored into the Database, this permitting the analysis of all data and real time monitoring.

COSMO PROJECT, SALERNO DEMONSTRATION

The COSMO (Co-Operative system for Sustainable Mobility ) project is part of the European Commission’s Competitiveness and Innovation Framework Programme (CIP). Its aim is to improve the deployment of mobility services or ITS applications, in order to better road transport safety and to reduce environment impact.

The project did not develop new systems but it contributes to make operational existing prototypes and pre-commercial devices in real-life road context, like RED-WINE system. The main objective of COSMO was to demonstrate the effects of these systems on the environment in terms of energy efficiency and environmental impact.

Systems developed in COSMO could be classified in different categories, one of these categories being the intelligent streetlight management.

The Italian Pilot Site, deployed in Fisciano, the campus of University of Salerno implemented several applications in the same geographical area integrated in an single architecture able to support advanced telematics services for a mobility sustainable characterized by an higher energy efficiency.

The type of the streetlight used within the pilot installation presented in this work is called FUTURLUX BEAM. The LED arrangement for this type is mounted longitudinally to the road ensuring the street lighting assists with the guidance. The control of the LEDs is integrated into a LED driver.

The key element of this application is the traffic adapted street light system with low energy consumption able to provide variable levels of luminosity and of power consumption. When traffic flow is low or no cars runs along the monitored path, a lower level of luminosity is sufficient and the streetlights can be dimmed to save energy.

There have been installed three RED-WINE WSN networks involving a total of 10 wireless nodes, in order to cover the marked from north, south and internal road.

The design below presents the streetlight management system described in the previous paragraphs. There are present 2 lines of lights (5 lighting points each) – in green and orange and three management WSN – gateways in red and WSN nodes in blue.
RESULTS

The intelligent streetlight management service relates to the use of street lights with two different levels of control (full power or energy saving) that reduce the electric energy consumption, since lights in full power operation are not needed at all night hours. The results obtained within COSMO are clearly positive; the initial expectative (hypothesis and target criteria) have been overcome, giving energy savings between 44% and 55%, depending on the level of control.

The system has been active for one month (May 2013) and the redundancy of the wireless nodes guaranteed the complete functioning of the system and data logging (information was stored regarding vehicle passages every minute). Furthermore, the carried statistical analysis show that the sample set is representative enough of the real population: the maximum distance from the observations data set mean value and the actual mean value are equal to 0.003481 kWh (standard deviation). (COSMO, 2013)

The total energy consumption per day is reported for these three situations:

- Traditional Sodium vapour lamp (SON) based streetlights (Baseline)
- LED technology based streetlights
- LED technology with control based streetlights (Operational)
As shown above there are high energy savings using the second and third system comparing with the traditional SON based streetlights. It should be noted that while in the first and second situation the energy consumption is always the same during the month (because the consumed power is always the same even if they assume different values), in the third situation energy consumption changes during the month of reference due to the different period of time in which streetlights are in full power and energy saving modes. In the same figure the average value of controlled LED situation is reported too.

CONCLUSIONS

Given the application performances registered, deployment of this type of solutions should be accelerated, starting with controlled areas like the ones represented by this pilot site, that can have less legal and exploitation constraints. The combination of the two technologies and the dedicated monitoring system (designed for road-infrastructure) makes the presented solution strongly adapted for the management of the street-lighting on extra-urban roads like interchanges or parking areas.

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No more traffic jams. Tradable reservations

1st IRF Europe & Asia Regional Congress & Exhibition

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ABSTRACT

Peak hour roadway congestion wastes time, resources and harms the environment. Traditionally, this was solved by widening roads. In the last 20 years or so we have increased capacity by adding ITS systems as well. In recent years we have looked at the demand side as well. Examples of demand management policies are road pricing, advocating flexible working hours, and even paying people not to drive during rush hour.

This paper investigates a new approach to bypass the negatives that are associated with implementing road pricing schemes. (There are a lot of initiatives but only few are realized). It proposes a reservation system that distributes the available road capacity over all commuters in a ‘free market’.

A driver makes his travel plans known through an intention in the reservation system. The reservation platform checks if the capacity is available and if so, generates a reservation number. If there is no capacity, a free alternate arrival time or longer route is proposed. The provided service is free flow conditions on the network allowing commuters to accurately estimate travel times. A commuter can decline the generated alternative route or time. In this case, he has the option to buy a reservation from another commuter who already has a valid reservation. Whenever a trade is made, both the reservation holder and the buyer are satisfied. The reservation holder receives a benefit that off sets the negatives of changing his travel plans, the buyer values his trip higher than the cost of buying an existing reservation.

Benefits of this approach are:

- It is not a ‘driver’ tax and therefore current fiscal policies do not have to change. This is one of the main reasons why it is so difficult to implement road pricing.
- Since price levels during rush hours are determined in the free market trading platform, it excludes political influence on these price levels. Policy makers do not have to explain why driving costs money and this will make it easier for politicians to sell this idea to their constituents.
- Free riders in the system generate their own congestion. This gives enforcement entities a reasonable cause to stop vehicles and check the reservation. This lowers the necessity of installation of in-vehicle or roadside detection systems. This reduces privacy issues, a third reason why it is road pricing is difficult to implement. pricing is difficult to implement;
- Reservations enable Traffic Control Centers (TCC) to accurately estimate traffic demand. This
International Road Federation

gives TCC the opportunity to adjust capacity by ITS systems where available such as commuter lanes, reducing speed limits and planning lower capacity during road works.

- A reservation and trading system opens new markets for service providers to provide services that operate on PC’s, smartphones, navigation systems and reservation call centers, reducing the cost on hardware installation and service updates.

INTRODUCING ROAD PRICING

Road pricing has evolved over a long period of time from tolls, to cover capital and operational costs, to a congestion charge or cordon charge that helps road agencies and operators manage traffic through a pricing mechanism (1). Let’s look at infrastructure as a market, with a supply and demand, to understand why this principle works. On the supply side, we see that the capacity of the roads are static and can only be changed dynamically through advanced ITS systems or by physically adding lanes that increases static supply of roadway capacity. The economy as a whole generates the need for transporting goods and people over this network. Whenever the demand for transportation in a certain time frame is higher than the capacity of the network, congestion occurs. Without a pricing mechanism there is no possibility for the market to generate an optimum where demand meets capacity. In economic theory, we speak of imperfect markets. Road pricing has been debated extensively as one of the most promising ways to reduce congestion and generate revenue to offset externalities such as hidden costs related to pollution.

Road pricing can be implemented in different forms such as cordon pricing in London or the Singapore example where variable pricing schemes depend on time of day and how far and where vehicles travel. The external effect of congestion, combined with externalities is priced into the trip, thus reducing demand for transportation.

Why it does not work

When a road agency or private road operator implements a road charging scheme, one of the prerequisites is that it has to be fair and every motorist has to pay the charge when using the network. This directly affects the private business case or undermines the principle that taxes have to be paid by all users. Infrequent or holiday users have to pay as well. Depending on the tariff structure, this results in a closed system where origins and destinations have to be calculated, vehicle type has to be recorded and / or time of day is recorded. Such systems may include roadside infrastructures such as traditional toll plazas or gantries with detection equipment (i.e. license plate recognition camera’s, RFID sensors or in vehicle GPS based location devices that record the time and location of the vehicle). Recording all this information for the purpose of a road charge raises issues of privacy. Ensuring that everybody who uses the road pays, is costly.

A second problem arises when governments implement road charging on existing roads. Commuters have always used the road for ‘free’. Roads are paid through a means of indirect taxes such as vehicle registration fees, fuel taxes and vehicle purchase taxes. In the Netherlands, implementing a road charging scheme was only politically feasible if it met the condition that overall tax income would remain the same, thus resulting in changing vehicle registration and purchase taxes. In principle, a fuel tax and road charge are the same in that they tax the use of transportation. Taxing the ownership of the vehicle, in the case of a purchase tax and vehicle registration tax, is different. Changing tax schemes results in significant affects in spendable income for individual households. It also changes the first and secondary market for car sales.

These unknown effects make households generally oppose road charging schemes that are founded on the idea of loss aversion (3). The principle of loss-aversion states that avoiding loss, i.e. access of a free road, is more important than acquiring gain, through faster commute times or additional road extensions that
can be funded through the revenue.

Setting the ‘right’ price for a charge is also complicated from an economic standpoint. The demand for transportation is relatively inelastic in terms of cost and elastic in terms of time. A higher price does not necessarily mean that more people decide not to travel but that people likely have a greater ability to change their driving behavior to an earlier or later hour thus making better use of the infrastructure over a 24 hour period. A time dependent road charge will likely move commuters to an earlier or later time frame with the result that congestion starts earlier and lasts longer. Since this is a dynamic effect, commuters will react strategically to any pricing scheme adjustment. Since pricing is influenced by political policy agenda’s, a rate change is time consuming and unable to set the right price at any given time. This means that although road charging reduces demands it is unable to fully utilize the available capacity by a truly variable pricing mechanism.

A road charge is a toll or tax generating a revenue stream from private households and companies to a government or road operator. All road users must pay the road charge. This means less money in your pocket. These revenue streams are often earmarked to expand road capacity, add missing links in the network or expand transit services to give commuters alternatives to the road charge, allowing them to change their behavior. In the Netherlands, several pilots (www.spitsscoren.nl) were launched where commuters receive a positive incentive such as money or rights to play in a lottery when they change their driving behavior and avoid the rush hour in the morning commute (4). This positive incentive offsets the negative tone of road charging but proves to be economically unfeasible. It reverses the revenue stream from the government to commuters.

Summarizing, road charging is difficult to implement due to the lack of benefit for the individual and high political risks that are associated with it. Road charging has a negative ‘tax’ tone and is often linked to tax reform, making the implementation process too timely (5). It has high implementation and enforcement cost, reducing the net revenue streams and it is difficult to adjust the road charge user fees to dynamically changing traffic patterns shifting traffic to other areas in time or place.

**A NEW APPROACH TO SOLVE CONGESTION**

In the introduction, congestion was defined as an economical problem where demand and supply are not in balance. A road can carry traffic close to its design capacity. When the design capacity is met a small disturbance causes drivers to slow down, the ripple effect comes into play and reduces the throughput measured in vehicles per hour (6). For optimum throughput the demand on any road section should be close to, but not exceed, design capacity of that section. When this condition is met traffic flows in free-flow status. Informing road users of the available capacity helps them in making a decision over what route they will take and at what time they will travel. In order to facilitate this decision making process, we propose a new approach to solve congestion.

**Reservations**

We ask each road user to make his intention of the trip known in an online reservation system before he starts with his trip. The reservation system checks the desired arrival time and then calculates back the trip over the network. The reservation system has the entire design capacity of the network in mind and has the condition that it does not allow more road users than design capacity.

When there are fewer reservations than the road can carry a reservation is made. The road user knows that he will arrive on time because the system is designed in such a way that it does not allow more cars on the road than the design capacity of the road. The road user will make the trip in free flow status, which is the minimum travel time obeying the speed limits. A true service.
When the intention of the trip cannot be made because the capacity is already reserved, the system generates alternatives by proposing an earlier or later arrival time on the shortest and quickest route. This alternative is based on the presumption that people are more flexible to change their travel behavior in time than to decide if they have to make the trip at all (elasticity in time). The road user can decide to take up one of these alternatives and make the reservation. Although the road user might have to leave earlier, he still makes the trip in free flow conditions.

Alternatively, a secondary or longer route over the network, is calculated and proposed. Note that this increases costs for the road user measured in time and fuel costs. It also increases emissions, thus external costs. The economic decision lies with the road user and it is expected that the external costs of additional emissions are excluded from his decision. Including the additional emissions seems fair for this second best alternative.

**Do you need to pay for a reservation?**

The mean function of the reservation system is to prevent over demand and congestion on the road network and show road users alternatives. From that point of view and the premise that roads are already financed through different indirect taxes there is no need to charge. Recovering the additional costs of implementing and maintaining the online platform is enough. This can be realized through a flat fee per reservation or a fixed monthly fee independent of the number of reservations.

**If we do not pay for the reservation can we sell it to another driver?**

The pilots in The Netherlands show that people are willing to change their travel behavior if they receive a positive incentive. When we include this idea to the reservation system it could work as follows: a road user who made a reservation for a trip in the future is willing to change his trip in time or use an alternative if he receives a benefit. There are also road users who are willing to pay a price to get the reservation they need instead of using one of the alternatives that the reservation system generates. Bringing reservation holders and potential buyers together in an auction creates a secondary trading market where pricing of scarce network space can take place.

A trade will only happen if there is more demand than there is capacity. Otherwise, people will use the free reservation system. Whenever a trade is made both the reservation holder and the buyer are satisfied. The reservation holder receives a benefit that offsets the negatives of changing his travel plans, the buyer values his trip higher than the cost of buying an existing reservation. The economic value of the road becomes visible if trades are made.

No revenue stream is generated to the government. Combined spendable income of the holder and the buyer of the reservation stays the same. Note that when the seller still wants to make the trip he has to go back to the reservation system and put his new intention into the reservation system at an alternative time.

**Free riders and enforcement strategy**

If the reservation system works and the design capacity reflects actual network performance then congestion cannot occur. This has another big benefit that is related to enforcement. Road users without reservations cause over demand and possible congestion. Whenever there is congestion this means that there are drivers on the road without a reservation. These free riders can be penalized through police enforcement in a similar way as it is mandatory for a driver to have a driving license and vehicle insurance. Government does not check before you start your trip if you have a license and insurance, neither does it have to check if you have a reservation. A congested road means that there are likely road users without reservations giving police or other enforcement agents a reasonable cause to stop vehicles and check reservations.
The principle that violators cause congestion also eliminates the need for expensive roadside infrastructure or in car systems to track and validate each road user’s actual trip with a centrally stored reservation. This makes implementation costs low and eliminates the logistical problem of installing and maintaining and servicing in car systems in existing and new vehicles.

The reservation system can be designed on the basis of anonymity of design. It does not need to know who you are, what car you drive nor where you intend to go. It simply checks the roadway capacity and generates a trip ID with a unique reservation number that can be printed/sent to you by SMS or an APP on your smartphone. The trip ID is not tied to you or your vehicle and thus becomes transferrable to other users. When asked by the police to show your reservation you simply show the trip ID, with route and time information on paper, SMS or through your APP and it is checked on the spot.

Road users without reservations who use the network in off peak hours are violators to the principle but do not cause economic harm to others. There is still free flow condition for all and trading of reservations will not happen. There is thus no need to enforce. When implementing a reservation fee to cover costs on a per reservation basis the need for enforcement is also required in off peak hours because the reservation fee per user can be lower if more reservations are made. Therefore, it is required that everybody uses a reservation system. A flat reservation fee per month independent of the number of reservations made eliminates the enforcement costs at off peak hours.

**POSSIBLE IMPLEMENTATION SCENARIOS**

The Stockholm Road cordon charge project is the only road charging project implemented by means of a referendum, after a short pilot situation that showed the benefit of fewer congestion to the people of Stockholm (7). All other road charging projects on existing road networks are in place in large due to bold leadership from politicians. A pilot situation showing the benefit to the road users of free flow seems an elegant approach. The pilot should be large enough in area to allow people to make use of alternative less congested routes and needs to have transit options. It is important that the commuters have easy access to the (wireless) internet to allow them to communicate with the online reservation system. The pilot does not have to cover a large time period since effects will be eminent on the first day that the pilot runs. A corridor or city ring network can be used. Special events that draw a lot of traffic for a short period of time such as the World Cup or Olympic Games can be used as a political accelerator for the pilot.

The system consists of three major components:
- An online reservation system that checks available capacity and distributes reservation slots on the network
- An online trading platform to trade existing reservations between road users
- An enforcement system to ensure that road users have valid reservations

The road agency can implement the reservation system and provide access to it. Access to the reservation system can be provided through service providers. Compare this with booking a hotel room. We can use the website from the hotel or use web based search agents. Allowing search agents to make a reservation creates opportunities for your navigation software to become a service provider or for your electronic agenda that makes the reservation for you and schedules the trip in your agenda. Creating different channels to make a reservation enables consumers to choose the best service provider. The government can but does not need to be the service provider. Similar arguments can be made for the trading platform. A government that allows reservations to be traded between road users does not have to implement and operate the trading platform. There can be several trading platforms that also compete for business.

**Risks of scalpers and speculators**
In order to make the system work we have to make sure that speculators and scalpers have little chance of
success. Implementing a rule in the reservation system that a user cannot hold more than one reservation
in a time slot is a start. Implementing a second rule that the following trip starts at the last destination
ensures that people do not strategically make reservations in areas where they do not intend to drive. Both
rules prevent large scale speculation and scalping collecting more than one reservation for resale at a
higher price.

We already discussed free riders using the network without a reservation and that this needs to be
enforced. Let’s assume now that a lot of people make a reservation but do not use them. This group can
be divided into people who intend to use the reservation and at the last moment change their plans and
people who make the reservation for the purpose of possible resale, thus speculation. Both groups cause a
demand on ‘paper’ which meets design capacity that is not actually going to happen. This results in
trading reservations among people who will use the road network, change their travel plans when there is
no actual need for it.

The group that changes its behavior at the last moment misses out on the possible benefit of trading the
reservation. Making the sale on the secondary trading market easy will likely ensure that these
reservations are traded, thus dropping the price in this market. When a speculator can only hold one
reservation at a time it limits his market and effect. A rotating pool of users who have the right to make
reservations ensures that everybody has the right and opportunity to make a reservation in the reservation
system periodically, thus drives for free.

**Economic injustice**

Dynamic pricing of scarce capacity during congestion hours through a trading platform can lead to high
prices. Lower income groups may be unable to pay such prices. The reservation system can deal with this
situation in two ways. Proposing a free alternative to arrive at an earlier time or use a secondary longer
route generated in the reservation system. Using a system where all users have the opportunity to make
a reservation for free through a rotating reservation pool enables everybody, including the low income
groups, to access a free road. The pool can be 1/5 of the users ensuring everybody can make at least once
a week a free trip. When people share their reservation and commute together it already reduces demand
by 20% and lowers prices.

**Other benefits**

When everybody uses the reservation system it creates benefits for Traffic Control Centers in that they
know beforehand what the expected demand for traffic will be at any given time. Traffic Control Centers
can move from a dominant reactive strategy to a more proactive strategy. When the reservation system
shows demand close to capacity it allows the Traffic Control Center to implement Dynamic ITS strategies
in a timely fashion to increase temporarily the capacity of the roadway. For example, lower speed limits,
commuter lanes and open the shoulders for traffic. This decision from the Traffic Control System can
then be included in the reservation system to allow additional traffic on the specific network session.

A major cause of congestion are narrowed or closed lanes due to road works. The reservation system
enables Road Agencies to lower the capacity or the roadway during road construction periods. The
lowered capacity means that trading between road users will start earlier. The trading makes sure that the
highest valued trips make use of the scarce capacity, thus generating the least amount of economic loss
for society as a whole. Congestion during road works will be eliminated.

**CONCLUSIONS**

Introducing a price mechanism on congested roads to reduce demand is a promising strategy.
Implementing road charging projects is difficult because of the high costs associated with it and the negative tone of introducing a tax or toll on services that were considered free. Road charging makes you feel the pain financially but does not guarantee a free flow condition. The underlying principle of loss aversion makes it difficult for policy makers to create support for these projects. The principle of changing behavior through a positive incentive, that is currently used in pilot projects in the Netherlands, shows that people are willing to change their travel plans for a financial benefit.

A reservation system that distributes the available capacity in the network over the road users’ limits the number of cars on the road and generates a free flow status. The road agency can deliver a true service, driving at the speed limit to your destination without delay. The reservation gives road users insight in the available capacity so that they can make informed decisions.

Creating a trading system where individual road users can buy and sell their reservations whenever there is more demand than the reservation system can issue, maximizes the principle that people are willing to change their behavior if they receive a benefit. It also ensures that the highest valued trips are made. Giving road users access to make reservations in the system, on a rotation basis, ensures that everybody can acquire a free reservation. This reduces the economic injustice associated with high valued trips.

A trading system where people can sell reservations creates an opportunity for speculation and scalpers. Allowing only one reservation per user in a specific time and tying a user to a license plate or drivers license eliminates the opportunity to make multiple reservations.

With the reservation system traffic jams due to congestion become a thing of the past. When they do, free riders are in the system. The congested area gives the enforcement entities reasonable cause to stop vehicles and ask for reservations. This enforcement principle makes roadside equipment unnecessary for logging origins or generating trip destinations, nor is it necessary to have in-vehicle systems. This reduces the cost for implementation, maintenance and service updates.

RECOMENDATIONS

Implementation of the system needs further investigation. Special attention should be given to the design capacity of roads and how to dynamically model this capacity in the reservation system. Unforeseen circumstances related to weather and accidents also need to be modeled in the system. The idea of the reservation system is to keep it as simple as possible and empower road users to make economic decisions based on ‘choice’. Allowing them to trade and find an optimum, time and time again. A short pilot project or field test is recommended to validate these principles. The Stockholm project shows that road users who see the benefit of congestion relief are likely to vote in favor of a new system. Once the system is in place, other policy objectives can be incorporated that are related to vehicle emissions, revenue generation and/or tax reform.

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Traffic congestion in urban areas is a frequently encountered problem in many countries. This problem can be divided into two groups: recurrent and non-recurrent. The first one occurs routinely and is not triggered by a temporary event. However, the latter is generated in response to temporary events, such as bad weather conditions, work zones, traffic incidents or other non-recurring events. Studies have shown that more vehicle hours of delay result from unexpectedly occurring traffic disturbances rather than recurrent network overload during peak hours. Some of the temporary events, such as accidents, breakdowns or any type of obstacles that can cause induced traffic congestions are called the term incident in the traffic. Incident detection can be seen as a significant component of the overall incident management process. In this study, a literature review is presented on various incident detection algorithms and their real-time and simulation based implementations. An integration of flow and crash modelling that might be useful for developing incident detection algorithms is also discussed.

**Keywords:** Incident, traffic congestion, delay, detection algorithm, modelling.
1. INTRODUCTION

The current efforts for modelling and solution of traffic problems, such as the congestion and congestion propagation, are to represent the problem, and consequently the solution, in a time-varying, or dynamic, way. Realistic solutions to such problems can now be performed only if a certain amount of input data is obtained in real-time or in a time-varying fashion. Solution to traffic problems at various scales necessitates both the realistic modelling and the real-time processing of traffic flow. Deterministic and/or stochastic traffic flow models, that have a wide range of application domains, may be simply evolved to account for the issues, such as within-day dynamics and peak-hour flow variation. A more complex problem of interest is to quickly specify and model the effect of non-recurrent events in traffic flow, such as an accident, and consequently to maintain the stability of flow. In order to detect the ‘incident’, noted as the main cause of the non-recurrent congestion in the relevant literature, and manage the overall traffic flow propagation a number of approaches and methods are utilised.

With the motivation of dynamically detecting and predicting variation on traffic flow conditions, including incident and accident based propagations, the present study aims to develop incident detection algorithms, by making use of varying traffic flow theories that represent realistically the spatio-temporal variation of traffic flow, and evaluate their performances within a holistic approach where flow modelling and crash modelling frames will be integrated by coupling specific simulation platforms.

2. LITERATURE REVIEW

Because of conducting model that contain area of traffic flow and crash dynamic in existing incident and accident, the literature is presented two main subtitle.

Congestion is a major transportation issue causing safety problems and huge economic lossess while affecting almost every individual every day. According to Federal Highway Administration (FHWA) 25% of road congestion is attributed to traffic incidents, such as crashes, disabled vehicles and spilled loads (FHWA, 2005) Due to different reasons congestion can be classified into recurring and non-recurring. Recurring congestion results from demand exceeding supply over a certain time or space. Non-recurring congestion usually caused by occasional events, e.g, incidents, work zones and special events.
Many measures have been used to mitigate recurrent congestion for years, such as ramp metering and hard shoulder running. However, only a few previous studies systematically evaluated and compared the effectiveness of such strategies in combating non-recurrent congestion. Incident detection can be seen as a significant component of the overall incident management process. Majority of the type of this algorithm which catch the irregularity of traffic flow is the function of variation of capacity and occupancy.

Incident detection algorithm depends on highway management conditions, geometric design of road, environmental conditions, variation of vehicle classification in flow, distance between sensors, time and severity.

R. Weil, J. Wootton and A. Garcia Ortiz discussed the development of a new novel time indexed anomaly detection algorithm. They establish norms as a time dependent function for each station by integrating past “normal” traffic patterns for a given time period.

Asim Karim and Hojjat Adeli present a new two-stage single-station freeway incident detection model based on advanced wavelet analysis and pattern recognition techniques. Wavelet analysis is used to denoise, cluster, and enhance the raw traffic data, which is then classified by a radial basis function neural network. An energy representation of the traffic pattern in the wavelet domain is found to best characterize incident and nonincident traffic conditions. False alarm during recurrent congestion and compression waves is eliminated by normalization of a sufficiently long time-series pattern. The model is tested under several traffic flow scenarios including compression wave conditions. It produced excellent detection and false alarms characteristics.

Michael Taylor and Kun Zhang have studied a new automated incident detection framework for both freeways and urban arterial roads. A common modular architecture that includes a special data processing module to handle site specialties is applied to the freeway algorithm (TSC_fr) and the arterial road algorithm (TSC_ar). Bayesian networks are constructed to store general expert traffic knowledge and perform universal incident detection. The TSC_fr algorithm is evaluated using a large number of field incident data sets, and the TSC_ar algorithm is tested using simulation data. The testing results are very encouraging. It is found that both detection rate (DR) and false alarm rate (FAR) are not sensitive to incident decision thresholds. When the decision threshold is above the certain level, both DR and FAR reaches a very stable region. This is the unique feature of the TSC algorithms. The results also demonstrate algorithm transferability is achievable under the new incident detection framework.
Dia and Rose (1997) proposed a multi-layer feedforward (MLF) neural network incident detection model. The result of the comparative performance evaluation clearly demonstrate the substantial in incident detection performance obtained by the neural network model and also show how improvements in model performance can be achieved using variable decision threshold.

Srinivasan et. al. (2000) developed a hybrid artificial intelligence technique, with fuzzy-logic and genetic-algorithm technique, for automatically detecting incidents on a traffic network.

Ivan (1997) developed a new technique based on data fusion methods using multiple data sources; inductive loop detectors, and travel times collected from probe vehicle travelling through the street network.

Peter Martin and Joseph Perrin examine a range of incident detection technologies to determine a recommended combination of approaches for use in the Utah Department of Transportation (UDOT) Advanced Traffic Management System (ATMS). The technologies that were examined are computer-based automatic Incident Detection (AID), Video Image Processing (VIP), and detection by cellular telephone call-ins.

Manoel Mendonca developed a self-learning, transferable algorithm that requires no calibration. The dynamic thresholds of the proposed algorithm are based on historical data of traffic, thus accounting for variations of traffic throughout the day. Therefore, the novel approach is able to recognize recurrent congestion, thus greatly reducing the incidence of false alarms. In addition, the proposed method requires no human-intervention, which certainly encourages its implementation.

3. METHODOLOGY

In this study, incident detection, inspection and detection process will be modelled by bringing in method that provide detection of sudden and severe differentiation. Before this model, flow modelling and crash modelling will be integrated by integration of related software. According to literature review various methods was decided since it is widely accepted, frequently used and advised one which could be compared with other methods. At the subtitles below presents respectively various approach for incident detection which containing the main modelling approach summarized by referring the related data, some methods for comparing proposed methods and crash simulation.
3.1. Various Approach for Incident Detection

3.1.1. Sample – Based Method

The method generally uses the capacity and occupancy data taken by induction detector. In this algorithm, threshold that has normal flow condition is determined in advance and the rest of the values are identified as out of the normal. Determining the threshold is hard and to take lots of time.

1. California Algorithm TSC 2
2. California Algorithm TSC 7
3. California Algorithm TSC 8
4. APID (All Purpose Incident Detection) Algorithm
5. PATREG (Pattern Recognition) Algorithms

3.1.2. Catastrophe Theory –Based Method

Catastrophe Theory takes its name from the sudden discrete changes that occur in one variable of interest while other related variables are exhibiting smooth and continuous change (Persaud and Hall 1989). These variables are speed, flow, and occupancy. When speed drops dramatically without a corresponding increase in occupancy and flow, the alarm sounds. In this regard, Catastrophe Theory based algorithms are able to differentiate between incidents and recurring congestion. Congestion builds up slowly, while incidents cause a sudden queue to develop and drastic changes in speed to occur. The algorithms exploit this phenomenon. The difference between Catastrophe-based and pattern-based algorithms is that pattern-based methods rely on individual variable and pre-set thresholds, while the catastrophe method uses multiple variables and compares them to previous trends in data for recurrent congestion. The only type of algorithm that fits into this classification is the McMaster algorithm (Persaud and Hall 1989).
3.1.3. Statistical Methods

Statistical methods generally enable real time data to compare the predicted data. When occurring any variation of traffic flow values in accordance with predicted one, occurring the incident/accident situation can be said.

1. HIOCC (High Occupancy) Methods
2. Stochastic Methods
3. SND (Standard Normal Deviation) Algorithms
4. DES (Double Exponential Smoothing) Methods
5. Filtration Methods
6. Bayesian Based Methods
7. SSID (Single Station Incident Detection) Algorithms

3.1.4. Artificial Intelligence – Based Method

Artificial Intelligence (AI) is a recent development of AID algorithms. These algorithms detect incidents by either a rule-based algorithm or an algorithm that has learned to recognize incident patterns. Neural Network (Stephanedes 1995) and Fuzzy Set Logic (Chang 1994) are the main AI applications that have been applied to AID.

3.2. Some Methods For Comparing Proposed Methods

3.2.1. California Algorithm #7 (TSC 7)

California Algorithm #7 is a comparative algorithm which uses preset thresholds to classify current road condition (Levin and Krause, 1978). California Algorithm #7 needs only occupancy data from two adjacent detector stations. Algorithm calculates spatial difference in occupancy, OCCDF, and the relative spatial difference of occupancies, OCCRDF. In addition to these two data, algorithm uses occupancy values of obtained from downstream detectors. Calculation process of OCCDF and OCCRDF are given below;
OCCDF(i,t) = OCC(i,t) – OCC(i+1,t),

OCCRDF(i,t) = (OCC(i,t) – OCC(i+1,t))/ OCC(i,t)

where i denotes the detector station number and t denotes the time period. OCC(i+1,t) is the occupancy value, which is obtained from detector station (i+1) in time period t. Downstream occupancy value, OCC(i+1,t), can also be represented as DOCC. California Algorithm #7 basically calculates OCCDF and OCCRDF values and obtains DOCC value from detector stations and compares these inputs with 3 preset thresholds, T1, T2 and T3. T1 is the maximum value of the OCCDF under normal conditions, T2 is the maximum value of the temporal difference in downstream occupancy (DOCCTD) under normal conditions, T3 is the maximum value of the OCCRDF under normal conditions. DOCCTD can be calculated with the equation below.

\[
\text{DOCCTD} = \text{OCC}(i+1, t) - \text{OCC}(i+1, t+1)
\]

After comparisons of thresholds and inputs, algorithm decides in what state the road currently is. There are 4 identified states for California Algorithm #7. Road is in state 0 when there are no incidents, in state 1 when there is a possibility of incident but still there aren’t any detected incident, in state 2 when the incident is detected and state 3 when incident continues. Logic behind the California Algorithm #7 can be found in Levin and Krause, 1978.

![Fig.3.1. California Algorithm #7](image-url)
3.2.2. APID Algorithm

APID algorithm was proposed for COMPASS advanced traffic management system, which is implemented in Toronto Metropolitan Area (Masters et al., 1991). In addition to OCCDF, OCCRDF, DOCCTD, DOCC, APID algorithm needs relative temporal difference in speed, SPDTDF as input. Calculation procedure for SPDTDF of APID is given in equation below.

\[
SPDTDF(i,t) = \frac{(SPD(i,t-2) - SPD(i,t))}{SPD(i,t-2)}
\]

SPD(i,t) is the speed data obtained from upstream detector in time period t. APID algorithm can only be executed when all the data above are derived. APID algorithm uses 4 different states to categorize road conditions which are exactly same with California Algorithm #7. APID algorithm contains 5 major routines, which are general incident detection routine, light traffic incident detection routine, medium traffic incident detection routine, compression wave test routine, persistence test routine (Masters et al., 1991). APID algorithm contains 11 threshold parameters and 6 control parameters, which are briefly explained in Table below.

<table>
<thead>
<tr>
<th>Control Parameters</th>
<th>Symbols</th>
<th>Default Value</th>
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<tbody>
<tr>
<td>Compression wave test enabled/disabled</td>
<td>CW_TEST_ENABLED</td>
<td>Disabled</td>
</tr>
<tr>
<td>Persistence test enabled/disabled</td>
<td>PST_TEST_ENABLED</td>
<td>Disabled</td>
</tr>
<tr>
<td>Medium traffic incident detection enabled/disabled</td>
<td>MED_TRAFFIC_INC_DETECTION_ENABLED</td>
<td>Disabled</td>
</tr>
<tr>
<td>Light traffic incident detection enabled/disabled</td>
<td>LIT_TRAFFIC_INC_DETECTION_ENABLED</td>
<td>Disabled</td>
</tr>
<tr>
<td>Compression wave test period</td>
<td>CW_TEST_PERIOD</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Persistence test period</td>
<td>PST_TEST_PERIOD</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Light traffic flow threshold</td>
<td>TH_LIT_TRAF</td>
<td>20</td>
</tr>
<tr>
<td>Medium traffic flow threshold</td>
<td>MED_LIT_TRAF</td>
<td>60</td>
</tr>
<tr>
<td>Incident clearance threshold</td>
<td>TH_INC_CLR</td>
<td>-0.4</td>
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<tr>
<td>Persistence test threshold</td>
<td>TH_PT</td>
<td>0.1</td>
</tr>
<tr>
<td>Compression wave test threshold 1</td>
<td>TH_CW1</td>
<td>-1.3</td>
</tr>
<tr>
<td>Compression wave test threshold 2</td>
<td>TH_CW2</td>
<td>-1.5</td>
</tr>
<tr>
<td>Incident detection threshold 1</td>
<td>TH_ID1</td>
<td>10.2</td>
</tr>
<tr>
<td>Incident detection threshold 2</td>
<td>TH_ID2</td>
<td>0</td>
</tr>
<tr>
<td>Incident detection threshold 3</td>
<td>TH_ID3</td>
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</tr>
<tr>
<td>Medium traffic incident threshold 1</td>
<td>TH_ME_ID1</td>
<td>Not used</td>
</tr>
<tr>
<td>Medium traffic incident threshold 2</td>
<td>TH_ME_ID2</td>
<td>Not used</td>
</tr>
</tbody>
</table>
APID algorithm employs 3 main incident detection check procedures, which are incident check procedure (INC_DETECT_CHECK), low volume incident detection check procedure (LO_VOL_INC_DETECT_CHECK), medium volume incident detection check procedure (MED_VOL_INC_DETECT_CHECK). General structures of these procedures can be found in Min, S.L.C., 2004.

Fig.3.2. APID Algorithm Procedure
Fig. 3.3. APID Algorithm ‘INC_DETECT_CHECK’ Procedure

Fig. 3.4. APID Algorithm ‘LO_VOL_INC_DETECT_CHECK’ Procedure
3.2.3. DES Algorithm

DES algorithm is a time-series based incident detection algorithm, which is proposed by Cook and Cleveland in 1974. DES algorithm basically calculates tracking signals for speed, volume and occupancy and compares them to pre-defined thresholds. Before the execution of algorithm certain initial values have to be determined which are mean absolute deviation smoothing factor, SFM, single smoothing factor, SFS, double smoothing factor, SFD, error in prediction, e, cumulative error in prediction in, E and mean absolute deviation, m. Calculation procedure of DES algorithm by using initial values is given in equations below.

\[
S(x, i, t) = SFS \cdot x(i, t) \cdot (1 - SFS) \cdot S(x, i, t-1)
\]

\[
D(x, i, t) = SFD \cdot S(x, i, t) + (1 - SFD) \cdot D(x, i, t-1)
\]

\[
e(x, i, t) = x(i, t) - D(x, i, t)
\]

\[
E(x, i, t) = E \cdot (x, i, t-1) + e(x, i, t)
\]
\[ m(x, i, t) = SFM \cdot e(x, i, t) + (1 - SFM) \cdot m(x, i, t-1) \]

Tracking Signal \( (x) = \frac{E(x, i, t)}{m(x, i, t)} \)

where, \( x \) is a traffic variable such as volume occupancy and speed, \( i \) is the detector station number and \( t \) is the time period. Other parameters of DES algorithm are briefly summarized in Table below,

| Table 3. Parameters of DES algorithm |
|-------------------------------------|-----------------|-----------------|
| Control Parameters                 | Definition       | Default Value   |
| VOL_TS_ENABLED                     | Incident Test for Volume | Disabled        |
| OCC_TS_ENABLED                     | Incident Test for Occupancy | Enabled        |
| SPD_TS_ENABLED                     | Incident Test Speed | Enabled         |
| T(V,i,t)                            | Volume Tracking Signal | 0              |
| T(O,i,t)                            | Occupancy Tracking Signal | 0              |
| T(S,i,t)                            | Speed Tracking Signal | 0              |
| TH_VOL                              | Volume Threshold  | To be determined|
| TH_OCC                              | Occupancy Threshold | To be determined|
| TH_SPD                              | Speed Threshold   | To be determined|
| ts                                  | Number of tests   | 0              |
| tse                                 | Number of test exceeds thresholds | 0              |

Fig.3.6. Incident Detection with DES Algorithm
3.3. Crash Simulation

In this study, it is aimed that, finite element method which calibrated based on vehicle dynamic crash simulation, as a fast and real timing method, flow simulation models were integrated, is indicated Figure 5.7. Suggested study need to be cross disciplines, such as crash, vehicle dynamics, traffic flow simulation and programming all those it depends on the eligible researchers work together as a team. It is not come across those kind of researches in the literature might be explained with those difficulties. Intelligent transportation system, problems faced in the practice, lack of detector, calibration, appropriateness of distance of detectors, or unpredictable traffic follow perceptions are attached importance as a solution towards management and simulation in order to calculate using multi vehicle and even fleet behavior.

3.4. Proposed Incident Detection Algorithm and Structure of Integrated Model

According to both methods that mentioned above and literature review, one of the most effective approaches for determining incident or the effect of incident is to examine variation on traffic flow in terms of speed, occupancy or density. The present study aims to develop incident detection algorithms, by making use of varying traffic flow theories that represent realistically the spatio-temporal variation of traffic flow, and evaluate their performances within a holistic approach where flow modelling and crash modelling frames will be integrated by coupling specific simulation platforms.

The approaches that will be developed for determining incident is basically the algorithmic process having component of both traffic flow modelling and prediction. Traffic flow simulation on highway network that has different scale with scenario of various non-recurrent congestion will be made in terms of existing traditional flow modelling approaches and simulation software that constituted by benefitting from these. The process of incident detection, inspection and management will be modelled through including methods that detect unexpected and serious variation on traffic flow. Therefore, in the present study, incident detection algorithm will be examined that tests various estimated methods whether intuitional or not as well as it will be compared with a new approach which determines variation on flow conditions. In order to test and compare, three measures of effectiveness have been used for comparison of incident detection algorithms those are false alarm rate, FAR, detection rate,
DR, mean time to detect, MTTD, for comparison of incident detection algorithms. However FAR, DR and MTTD measures used for comparison in most of the previous studies do not have consistent definition. In order to perform a clear comparison on algorithms clearly, these terms are defined. False alarm rate is the percentage of false alarms relative to the number of alarms. Formula of FAR is given in equation below

\[ \text{FAR} = \left( \frac{\text{number of false alarms}}{\text{number of total alarms}} \right) \times 100 \]

Detection rate is the ratio of detected incident periods to the total incident periods. Formula of DR is given below

\[ \text{DR} = \left( \frac{\text{number of detected incident periods}}{\text{number of total incident periods}} \right) \times 100 \]

Mean-time to detect is the average time an algorithm takes to detect incidents. Formula of MTTD is given in Equation

\[ \text{MTTD} = \frac{1}{n} \sum_{i=1}^{n} (t_a - t_{inc})/n \]

where \( n \) is the number of detected incidents, \( t_a \) is the time that incident detected and \( t_{inc} \) is the time that incident occurred.

Both in traffic production for scenarios which are created and tested, and calibrations of flow modelling in sample itinerary and network components with real measurements, the softwares according to study aim that can simulate accident/incident will be utilized. Therefore; location temporal change of traffic flow dynamics can be expressed differently benefiting from slim-size, mixed and coarse-size flow theories. The calibration on flow modelling studies will be done with microwave sensor data which collects traffic information such as volume and speed and occupation in different section on Istanbul urban highway-express road network and which was obtained from the Istanbul Metropolitan Municipality. With the help of these sensors placed along the urban highway-express road network and capable of highly accurate measurements, traffic flow measurement and variables can be determined in real-time. Directorate of Traffic and Transportation Department under the TÜBİTAK project no:111m415 and will be received under proposal, in case data is problematic and insufficient will be done with data obtained by the camera will record in the field. Therefore; with continuous position-temporal variation of the current variables representing the flow condition, the transitions between steady-unsteady flow conditions and such as zero volume-congestion as a
result of accident-incident discontinuities may occur can be identified. The accidents/incidents can be made synthetically with scenarios which will be defined by differentiating the factors such as flow characteristics, road geometry and driver behavior and it can be modeled in the simulation environment. Dynamics of vehicle crash, will be examined in the crash simulation environment and the outputs of particular vehicle will provide input to the flow simulation environment. On this occasion, crash-based calibration of flow model can be done. On the other hand, the dynamic of any clashes occurring in the variable traffic flow conditions, can be examined with the traffic flow-based calibration by utilizing the related simulation's traffic flow measurement. Mentioned bidirectional interaction, it will gain a integrated and simultaneous processing structure by assembling the related simulation software. The current variables either among themselves, or depending on time, or the position on the road (path length), or the different combinations of crash model outputs, will be discussed detecting both immediate and soft transitions in flow conditions as an output. Incident detection algorithm that dynamically identify changes in the current conditions with proper variables will be improved and the output compared with methods mentioned before and to test by means of determined scenario.

The detection method to be proposed, as shown in Figure 3.1 along with 3.6 in the previous subsection and that classify flow condition according to the predetermined threshold decision process will be express in the flow diagram and code will be written. To be proposed simple flow of control-management process as shown in Figure 3.7. In addition to the code to be written for determining incident, a top-level code will be written again in order to simulate an automated control and management system (flow shown in dashed lines in Figure 3.7).
Fig. 3.7. Proposed Integrated Model and Incident Management Process

References


13. Ullman, Gerald L. An Assessment of Potential Use and Benefits of a Statewide Call Box System in Texas. Texas Transportation Institute, College Station, TX, 1999.

ABSTRACT:

Ho Chi Minh City is the biggest city in Vietnam. With a fast growing economy in last twenty years, there are still many problems to be solved. The city has now over 8 million people. The biggest problem is traffic and transportation accidents. There is demand for public transportation including a bus network, elevated railway, Mass Railway Transport (MRT) and Light Railway Transport (LRT) network. In the last ten years, traffic and transportation accidents in Ho Chi Minh (HCM) city has become a fatal problem for the city’s residents, leaders, planners, engineers, and researchers. HCM city faces a big gape between the number of personal cars, motobikes and the slow developments of infrastructure. Traffic regulations are not obeyed, which makes transport in the city more complicated.

In the center of the city, there are ongoing construction of bridges, roads, and plans of several public transport routes like MRT, LRT, and BRT... Before planning and constructing stage, the demand forecast / survey must be done. In our study, we focus on the results of demand survey, traffic calculation of the road network when we are planning to build a bridge - THU THIEM Bridge II.

Keywords: road network, road capacity, traffic forecasting, traffic.

I. Introduction:

Ho Chi Minh City is the biggest city in Vietnam. Traffic jam and transportation accidents in Ho Chi Minh (HCM) city has become a fatal problem for the city’s residents, leaders, engineers and researchers. HCM city faces a big gape between the number of personal cars, motobikes and the slow developments of infrastructure. Traffic regulations are not obeyed, which makes transport in the city more complicated.

The traffic management is still not good enough. Intersections, signals, information and painting warning boards need to be paid more attention. The installation and renovation need doing more. The people’s committee of HCM city has traffic control and management of parking lots but not enough because of the rapid growth of the number of personal motorbikes and cars. In a recent survey, 94% of families in the city own motobikes (60% families have more than 2 motorbikes), 78% of residents use motorbikes. The number of motorbikes in the city is about 6 millions and the number of cars is around 550,000 as of 2014, and every year it grows 10%.

The environment has become pollute because of personal motorbike and cars.
Thu Thiem Bridge II is going to be built

The traffic in the peak hours is a daily problem. Parallel with the economic development, there are pressures of quick growth in population, quickly growing housing, especially high rise buildings. Thu Thiem is the new development in district 2, which needs one more bridge from district 1. Thu Thiem Bridge II is a new suspended bridge which connects district 1 with district 2. (Picture 1) There are many serious problems in this District 1, heavy congestion, so we have to have a study of the traffic behavior in this area. One of the problems in Ho Chi Minh is that there are a huge number of motorbikes, the number of motorbikes is almost 6 million, Ho Chi Minh City has more than 8 millions residents. There are 550 thousand cars and the number is rapidly increasing year by year. About the city transport planning we have done a master plan by a research of HOUSTRAN supported by JICA (Japan International Cooperation Agency) [1] in 2009. In this plan, a new proposing plan of the city government, the new situation and development of the area, we do a new research focusing on the traffic capacity of the existing roads and planning roads.

*Picture 1: Thu Thiem Bridge II is going to be built*
2. Traffic modeling and analysis

The research was sponsored by the department of transport of Ho Chi Minh City. The model focuses on the capacity of the roads and junctions around the Thu Thiem Bridge II. In this research we collect the information about

- Related researches about the roads, intersections in three most related roads: Nguyễn Hữu Cảnh, Tôn Đức Thắng và Lê Thánh Tôn road.
- The present time road network and the plan of the city government, the plan of the traffic outline, the traffic plan of these zones, and the plan of the related resident developments.
The survey on present traffic volume according for means of transportation, number of roads and intersections.

Recent transportation map and the planning map

The main tasks:

- Checking all the collected information.
- Survey on present traffic volume according for means of transportation, number of roads and intersections.
- Research on future road plan, future land use, social and economic plan of the city.
- Checking of the realization and progress of the transportation plan, the progress of public transportation, such as metro, bus system etc.
- Building the model for the forecast of the transport and the capacity of the roads basing on the software Citilab CUBE. The time for forecasting is years 2020, 2025 and 2030. The data base of the whole city transportation network was inputted several years ago with 265 zones in Ho Chi Minh City, in a big survey of the city planed 5 years ago. This time we update the new information related to the road network relating to the Thu Thiem Bridge II.

Next step, we will do the forecast of the related intersections using software VISSIM and SPECTRA basing on the time of the traffic signals. We can forecast the behavior and capacity of the intersections in year 2020, 2025 and 2030.

Because the finance for bridge construction is limited and also the land acquisition is independent, the bridge could be built in 2 or 3 times. Step one: first 4 straight lanes will be built. Step 2: the left turn way will be built. Step 3: The 2 right lanes will be built. (See the picture 3). So, we do modeling three scenarios of the bridge construction:

Scenario 1: Only four straight lanes
Scenario 2: Four straight lanes with left turn way (2 lanes)
Scenario 3: Four straight lanes with left and right turn way (each two lanes)

Picture 5:
Planning road in district 2

a) The traffic survey

Several surveys have already been made in this research area, including our research
of behavior and capacity of the Nguyen Huu Canh street facing the residential developments around Sai Gon River. This time, we do additional traffic survey mainly counting for the research in 7 locations (see Picture 6)

*Picture 6: Additional investing points and survey for the data collection*

CBD (Central Business District) will be replant for many walking streets and walking zones, also the riverside road will be build and the center city road, the Nguyen Hue road,
very near the bridge will be an only-walking street. There are also other projects in the center of city:
+ Planning to build a tunnel road beside the river.
+ Nguyen Hue and Le Loi will be walking streets (Only for walking and public transports)
+ Changing of several intersections.

b) **Modeling and forecasting**

Using the software Citilab CUBE [3] for forecast of demand of the areas (265 zones in HCM city), the procedure of 4 steps, walking mode, bicycles, motorcycles, cars, lorries, public transportation (buses and future Metro plan) in order to build a general model related to travel times and travel cost.

![Diagram of forecasting model](image)

**Picture 9: Step of forecasting model**

i. **Trip Generation**
Defining the number of commutings from other zones, social economic development index of the travelers and other relating factors. Defining total demand with output is the numbers of coming and going trips.

ii. **Trip Distribution**
Numbers of trips and distribution of trips among zones.

iii. **Mode Choice**
Defining the demand of each mode, each vehicle type.

iv. **Traffic Assignment**
In this step we define the choice of the travellers about the routes between 2 zones and the model choice.

*Picture 10: Network around the bridge*

**Results of the forecast**

*Picture 11: Forecast for Scenario 2 (4 lanes straight and the left ramp N1)*
According to the forecast in 2020, 2025 the volume of traffic will be quite far, but in year 2030, the volume of traffic will be high, still rather be stable in main roads, the volume will be very high in 2 roads in Le Thanh Ton street, Nguyen Thi Minh Khai Street.

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Scenario 1" /></td>
<td><img src="image2" alt="Scenario 2" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3" alt="Scenario 3" /></td>
</tr>
</tbody>
</table>

**Scenario 1**: 1.0 < V/C
**Scenario 2**: 1.0 ≤ V/C < 1.25
**Scenario 3**: 1.25 < V/C ≤ 1.5
**Scenario 4**: V/C > 1.5

*V*: Volume of traffic  
*C*: Capacity of road

*Picture 12*: Three scenarios in 2030

We propose to have an additional plan of the area. We should build a tunnel in a junction and expand a bridge with 2 lanes to 4 lanes in this period year time 2020-2030 so that the congestion can be mitigated.
3. Conclusion:

The THU THIEM Bridge II is going to be built in center of Ho Chi Minh City connecting district 1 with a new development and district 2 center. To avoid heavy traffic in center of city, our team does a traffic behavior research and forecast model.

According to the transportation plan, the existing situation, the city plan, the design of bridges with 3 scenarios, we will build a transportation model and calculating, forecasting the traffic situation of the road network around the bridge which is going to be built. We suggested that whole city need to develop an efficient public transport network is only the solution. City needs more studies, plans and strategies to develop the public transportation including bus system, rapid bus system, tramways, on-land railways, mono rail, elevated railways, underground railways, and also public passenger boards. In this area we proposed to build one more tunnel at the most traffic junction, extend one bridge on the riverside from two lanes to four lanes to meet the demand of the traffic.

Reference:
A case study of setting up quality public transport services in developing city of Indore, India

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Public Private Partnership, Use of ITS for Bus service, positive results, highly successful project, GPS/ GPRS use

India has a track of poor quality, unreliable & inefficient bus transport systems. This is a major contributor for rapid increase in personal transport such as 2 Wheelers in India. In order to change and manage the public transport system at Indore, India, a company “Indore City Transport Services Limited” was incorporated to manage it in the year 2005. Government of Madhya Pradesh was the majority of the stake holder of this company where individual also joined by providing buses on hire. The company was started with an authorized capital of just Rs. 2.5 Mn (approx. US $ 60,000) with public private partnership. Thus a high quality luxury bus service was launched in Indore. The highlights of the services introduced were, introduction of high quality high, capacity low floor Tata Starbus, GPS (Global Positioning System) for time & schedule management as well as vehicle tracking, computerized ticketing by handheld devices for accurate accounting & various data inputs, trained staff for enhanced service quality and affordability of tickets to general public. The public was charged the same amount even with higher comfort & better connectivity. The revenue model introduced was a win –win case for all the stake holders. The bus service which was first of it’s kind in India soon showing positive results. From initial uncertainty, soon the bus network was spread all over Indore due to Intelligent Transport Systems & use of relevant GPS/ GPRS technology. It has 6 lines currently which covers entire city very effectively. The operations were very well appreciated by the public. Today with quality operations the public transportation in Indore is by far the best & most comfortable in India. It ferries more than 1,50,000 passengers every day. Due to it’s success, many corporate have also helped to increase revenues by sponsoring In vehicle/ Bus stop advertisements. The project of introduction of such a comfortable, efficient & safe bus was well implemented. Now with expanding traffic & frequency of buses, the authorities have also introduced dedicated bus lanes in the city. But the projection of dedicated bus lanes has met with limited success. Many private vehicles are also found to be driving on these bus lanes breaching the rules. The Indore Bus Service now has become a matter of pride Many other cities like Bhopal, Ahmedabad etc. have followed the system & introduced similar services. This system is likely to be copies by many other Indian cities in time to come. Navi Mumbai city is exploring the options of launching similar services very closely.
INTRODUCTION

Public transport system in most of the Indian cities is not up to the mark. The city of Indore, which is situated in the state of Madhya Pradesh in Central India is no different. Indore is tier II city in India with an estimated population of approx. 2.7 Mn. The transport system which is the life line of the city & ferries maximum number of passengers every day comprises of old tempos (old fuel guzzling, noisy 3-wheelers) & locally build buses, owned by individuals & handful of government owned buses which were operated a skeleton service in the city. Due to persistent problem faced by the commuters, there was a steady build up of private vehicles to personal commutation as dependability on public transportation was very poor. Motorcycles, scooters & mopeds became more prevalent. The phenomenal increase of the vehicle population also resulted into many other concerns like increase in pollution levels, clogged roads, higher number of accidents & fatalities on the road. There was a general concern on how a person should travel in the city. Some of the other facts of the city are:

<table>
<thead>
<tr>
<th>Population</th>
<th>2.7 Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>150 sq.Kms (approx)</td>
</tr>
<tr>
<td>Average trip length</td>
<td>6 Kms</td>
</tr>
<tr>
<td>Average travel time</td>
<td>30 Minutes</td>
</tr>
<tr>
<td>Registered private vehicles in the city</td>
<td>0.5 Mn.</td>
</tr>
<tr>
<td>2 Wheeler / 1000 persons</td>
<td>230</td>
</tr>
<tr>
<td>Cars/ 1000 persons</td>
<td>27</td>
</tr>
<tr>
<td>% of private transport on 2 wheelers</td>
<td>80%</td>
</tr>
</tbody>
</table>

Indore is connected to other parts of the country through a well developed regional road system. Important amongst them are the Agra-Mumbai Road (NH-3), Ahmedabad Road (NH-51), Ujjain Road (SH-27) Khandwa Road(SH-27). There are several villages nearby which are connected thru these or support road network.

The intra-city public transport system is essentially road-based, with around 500 private minibuses, 550 tempos and 10,000 auto rickshaws. These are operated by a high number of independent para-transit operators on 67 mini bus routes. 400 LPG-based Maruti Omni vans have replaced the older tempos, and carry 7-8 passengers each along designated routes. In addition to minibuses, there are intercity buses running on state permits. Majority of the trips are made for work, business and education purposes, accounting for nearly 70% of total trips.
The then collector or District Magistrate of Indore took initiative & planned a successful public –private partnership in the bus transportation. He planned Indore City Transport Services Limited (ICTSL) an initiative to introduce luxury bus service. ICTSL was conceived with the idea of catering to the ever increasing demand for an efficient and cost effective transport system in Indore. While planning, other prime factors were:

- The service would cover entire city area thru various routes carefully planned.
- The bus service would be timely, prompt & dependable.
- The fares would be affordable. A common man should not feel the pinch of using the bus service.
- The bus service would be safe.
- Due to public- private partnership, many people / families would be benefitted by launching the services.

2. METHODOLOGY

Indore City Transport Services Limited was incorporated on December 01, 2005 with an objective to operate and manage the public transport system of Indore. Seven key people were identified to serve as the Directors on Board to create a local ownership of project. IMC (Indore Municipal Corporation) and IDA (Indore Development Authority) took 50:50 stake in Joint venture with an authorized capital of Rs 2,500,000. (US $ 55,550) The District Magistrate of Indore, was responsible for the execution of the project to run the bus service. The company is run as a public-private partnership. In fact the company is an umbrella organization in charge of implementing the new model. It is based on a public-private partnership model. The team provides the regulatory framework and the private companies operate the routes.

Initially, company identified and took permission for 18 high travel demand routes from Road & Transport Authority of State Government and started operation with 37 ultra-modern low floor buses. These city buses with 2 broad doors allowed passengers to board and alight quickly and easily, save time and fuel, and give better run-times and improved economy to the bus operators. Real time vehicle tracking and fully computerized ticket vending system were some innovations tried first time in the country. Operations & Maintenance and other regulatory measures were being exercised by the company.

A key concern was livelihood issue of existing Minibus operators and this was the main point of political contention. This was addressed by stating that no one is being forced out of market and a new competitor is coming just like any other bus operator. Tempos were phased out and tempo owners were given permits for new Maruti Omni Vans which replaced them. A big issue while involving government in any new project is financial liability on taxpayer. This stems from both recurring and fixed costs. As buses are owned and operated by operators there are no fixed or running costs for ICTSL on this count. Even “LED displays” and GPS devices are on books of respective private operators and thus there is no financial liability of government. All new manpower addition is also by private party and there is no problem of getting saddled with employees and their dues even when you are in loss as seen in and is common with other government corporations and even PSUs.

3. ABOUT ICTSL:

The bus system in Indore is run by Indore City Transport Services Ltd. which is a Special Purpose Vehicle that was created to plan, operate and maintain the bus service. It operates on public-private partnership by way of granting route permits to private bus operators to run their buses in the city. ICTSL currently runs 100 buses on 26 routes and has a ridership of 100,000 to 120,000 passengers per day. All ICTSL vehicles are monitored in real-time using GPS at the control centre on a GIS platform.

The ICTSL management is entrusted to Board of Directors. The board consists of six ex-officio members. The Executive Director is authorized to exercise all powers for effective management of the new transport system under PPP. This position is currently held by the collector of Indore district. In addition, Regional Transport Officer, Indore and Superintendent of Police, Indore (ex-officio) are special invitee members to all meetings of the Board. All the bus operators are also invited to the meetings of the board so that their valuable inputs are used for smooth and proper functioning of the company and the interest of operators is considered before taking any major decision. The management and control of all operations are with ICTSL.
In short, while setting up the PPP model, the key objectives set for ICTSL can be summarized as:

i. Specialized and effective regulatory agency at city level
ii. Establishment and maintenance of line of passenger coaches
iii. Support system for improving transport infrastructure
iv. Equitable Access to Poor and Incentive to upper Middle Class to opt for these buses

A uniform bus fare system i.e. single pass for all buses and all routes is followed. Pass revenue is shared subjected to strict adherence to routes and timings. Salary structure for all operators is consistent and the staff wears a common uniform. This ensures that public gets a feeling of using a single system only and does not become victim of manpower poaching among operators.

4. PUBLIC PRIVATE PARTNERSHIP MODEL

Under the Public Private Partnership model, the public agencies are in charge of infrastructure provision, service regulation, tracking, supervision and performance monitoring. The scope & work of each agency is defined above. Bus operations, ITS, issuance of seasonal passes and fare collection are contracted to private vendors based on an open bidding process.

ICTSL has made provisions of office spaces for each of the private operators within their own city premises. This allows for a regular update of services and concerns between both groups. Conflicts are identified and resolved in lesser time due to the healthy rapport between agencies. ICTSL also includes suggestions from bus operators on planning decisions. For instance, suggestions from operators were incorporated in the design of schedule of fleet induction.

5. FINALIZATION OF ROUTES

The city’s bus route network system has been scientifically planned and designed. Direction oriented “hub and spoke model” of routing has been adopted. Routes have been planned to ensure that office goers, students, and employees avail the services. It has been ensured that proposed routes cater to personal as well as work-place requirements. ICTSL started out with eighteen routes based on demand studies with permits from the Regional Transport Authority. These routes are in turn offered in an open bid system to private bus operators who are to pay the route premium as per the mutual agreement. ICTSL now runs 24 intra-city routes and 2 inter-city routes.
Color coding of routes and buses and their numbering has been carried out in such a manner that a commuter may easily identify the bus stop and intersection for convenient commuting.

6. FARES

The State Government is in charge of setting fare standards for buses plying in the limits of the Indore Municipal Corporation. The fare structure is designed in order to allow equitable access to poor, along with offering a competitive price for upper middle class to use buses instead of private vehicles. The setting of low fares is also intended to offer healthy competition to mini buses and tempos. Based on viability of the system, ICTSL finalized following fare structure:

<table>
<thead>
<tr>
<th>Distance (kms)</th>
<th>Fare (INR)</th>
<th>US $</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤3</td>
<td>6</td>
<td>0.09</td>
</tr>
<tr>
<td>3 ≤ d ≤ 7</td>
<td>8</td>
<td>0.126</td>
</tr>
<tr>
<td>7 ≤ d ≤ 10</td>
<td>10</td>
<td>0.158</td>
</tr>
<tr>
<td>10 ≤ d ≤ 13</td>
<td>12</td>
<td>0.190</td>
</tr>
<tr>
<td>13 ≤ d ≤ 16</td>
<td>15</td>
<td>0.23</td>
</tr>
<tr>
<td>16 ≤ d ≤ 19</td>
<td>20</td>
<td>0.317</td>
</tr>
</tbody>
</table>

1 US = Rs. 63 (as of 15 May 2015)

The monthly pass system had to become the backbone of the financial model. There were various options like Route Pass, Daily Pass, Student Pass, etc. but the company decided to keep it simple and start with a single pass for all priced at Rs.400. This would enable the passenger to travel unlimited for a month on any bus on any route. ICTSL also offers a monthly pass at Rs. 400 (US $ 6.35) The issuance and collection of monthly pass fees is operated by a private vendor, under a contractual agreement with ICTSL. There are 15 Instant Pass centres across the city to issue these passes. Currently, there are 23250 pass holders, most of which are Students who commute daily by these buses. Revenue from these passes is shared in the ratio of 3:2, favouring the private bus operators.

7. TRACKING VEHICLE & PASSENGER

Global Positioning System (GPS) has been installed in all buses with a central control room to manage scheduling and reporting of operational details such as distance traveled and stoppages. All buses have mobile phones with close user group network. This helps providing people with passenger information systems for the convenience of the commuters at all bus stops which shows on a LED monitor the exact time of arrival of the next bus. There is a control room from where the bus operations are completely handled. The display at the bus stop displays the vehicle/ route number, the
expected time & the next approval of the bus. The system has been well appreciated & accepted with over nearby connectivity provided by small vehicles (Omni Vans) which carry 7-9 persons.

8. FINANCIALS

The model had to be designed keeping in mind the motto of 'Minimum Investment with Maximum Returns' for all parties involved in the business. The financial model designed in house by ICTSL provided maximum profitability for the company as well as the operators. The operational aspect provided impeccable control for both the parties and fully computerized monitoring. The monthly operation cost for the bus is given below:

<table>
<thead>
<tr>
<th>Monthly Expenses</th>
<th>INR</th>
<th>US $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Km covered</td>
<td>7920</td>
<td>7920</td>
</tr>
<tr>
<td>EMI</td>
<td>40000</td>
<td>634</td>
</tr>
<tr>
<td>Insurance</td>
<td>10750</td>
<td>170</td>
</tr>
<tr>
<td>Diesel</td>
<td>158400</td>
<td>2514</td>
</tr>
<tr>
<td>Salary Staff</td>
<td>60500</td>
<td>960</td>
</tr>
<tr>
<td>Office Expenses</td>
<td>45000</td>
<td>714</td>
</tr>
<tr>
<td>Annual Maintenance</td>
<td>31680</td>
<td>502</td>
</tr>
<tr>
<td>Tyres, Misc repairs</td>
<td>18800</td>
<td>298</td>
</tr>
<tr>
<td>Total Expenses per month</td>
<td>373050</td>
<td>5792</td>
</tr>
<tr>
<td>Operating cost per Km</td>
<td>47.10</td>
<td>0.73</td>
</tr>
<tr>
<td>Operating cost in US $</td>
<td>0.73</td>
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</table>

Thus the operating cost of bus varies from INR 47 to Rs. 52 (US$: 0.73 to US $ 0.75)

9. ADVERTISEMENTS

Applications were invited from companies interested in taking the rights for advertising on the buses. Due to wider reach, good maintenance & high visibility, the demand for the advertisement also grew geometrically. Various advertisers participated and the highest bidder was Rs 30000 (US $ 476) per bus per month. This was a sort of record.
10. A WIN - WIN SITUATION

The experiment was win- win situation to all the stake holders as well as for all the commuters who has hailed the bus service in high esteem. The benefits were multiple.

**Public:** After experiencing bad days, traveling in the city is now quite a different experience. From less congestion to time savings, things have taken a volte face. Easy accessibility to different routes at comfortable timings is yet another value addition for Indore citizens. The system in itself generates positive externalities. Pollution and congestion is reduced which benefit non users also.

**Government (ICTSL, Indore Traffic, IMC, IDA, RTO)**
- Infrastructure Development
- Better city Transportation management

**ICTSL**
- High Revenue generation
- Minimal asset holdings
- Transferred most of the risk to private operators

**Private Operators**
Apart from no competition on routes they had bid for, they also got freedom from arbitrary policy changes (which was common with earlier system) as contracts are now 5 year long. The specific responsibility of the each agency is also well defined as shown here:
Two years later, Indore has a fleet of 98 modern, low-floor buses with computerized ticket vending. Electronic signboards at bus stops, announcing when the next bus is due, based on satellite data. Investment in the system has risen to Rs 40 crore, all done privately. The city has made a profit since inception; so have its six private partners who run the buses. Soon, it will have 500 buses. Indore is now quoted (with Bogota) as having the best bus service in the world.

III. GROWTH PHASE

Financial analysis for the last two years successfully captures the growth story. This has catered the passenger demand to a significant extent, but still there is scope for further development. The idea has gained huge popularity among Indore citizens and has been acclaimed countrywide. Also going in favor of the business opportunities in this model are the increasing levels of pollution, heavy traffic jams, scarcity of parking space etc. that plague the bigger Indian cities today. Adding to this is the galloping cost of fuel and there is likely to be a move towards public transport, away from personal transport.

One of the successes of city bus is that there has been no strike by operators for increasing fare as is common with intercity bus operators. Though MPSRTC, the state run & operated Transport System closed recently due to huge losses and negative net worth for long years and there were private operators already running buses. City Bus was asked to extend its service to nearby suburban towns like Pithampur (18 Km), Mhow (21 Km), and Dewas (40 Km).

Some of the basic principles which were learnt during the operations were: ‘one bus-one owner’ must be dispensed with, as it breeds inefficiency and makes operations economically unviable. Few operators with large bus fleets can ensure quality and most importantly have the scale and financial wherewithal required for quality improvements and learning best mutual practices. Secondly, ideally two operators should not be allowed to compete on the same route. This leads to speeding and accidents as drivers scramble to maximize revenue. Bus owners must get exclusive routes and earn revenue based on distance traveled, and this can be easily monitored by an affordable satellite system that tracks bus movement. Indore has a daily and monthly electronic pass, whose revenues are shared between companies. Lastly there must be a regulatory body which assesses demand, plans routes, fixes fares, gives out tenders, and monitors daily performance. Indore has a five person team which does this continuously, and this is the secret of its success.

12. KEYS OF SUCCESS

Key reason for success of this model was proper identification of risks and rewards and their allocation to the party which was best able to manage it. So traffic risk devolved entirely on private parties once they had bid a fixed revenue share to get that route and till date not a single bidder has complained of non recovery of his costs.

Though operational risks were transferred to operators, control and coordination by a government owned corporation meant that they were free of undue harassment by police, unsocial elements and passengers. ICSTL is also a party in a tripartite agreement between Bus manufacturers and operators thus giving a comfort to manufacturers about future orders and also helps in reducing cost of financing buses by operators as each bus costs Rs. 38 lakhs (US $ 60317) at the time when the project was launched (now the cost is Rs. 44 Lakhs which is US $ 69841) by making lenders comfortable though not directly making any commitment. All buses go to a centralized depot and follow uniform color coding, driver uniforms, signage etc. to create uniformity and passenger comfort.
Another improvement over existing system was behavioral training imparted to drivers and other staff by safety & management consultants. ACE conducted few programs for driver’s training for the drivers at ICTSL Indore which covered finer driving aspects & also behavioral aspects & managing stress levels.

Another factor to the success is the low ticket rate. Many commuters were forced to think that twice before taking their vehicle out every day as commuting is much more economical with this system.

Customer satisfaction and operator satisfaction make this model unique and a win-win situation for all. In fact the model was copied in almost all major cities of Madhya Pradesh , India (Bhopal, Gwalior, Ujjain, Raipur and Bilaspur) and even outside the state i.e. Ludhiana, Jalandhar, etc., thereby making ICSTL richer by almost a Rs. 100 Lacs ( US $ 158730) in consulting fee only.

13. EMERGING CHALLENGES

The model has not been free from flaws. Though it has significantly reduced the accidents by public vehicles and curbed labor militancy due to drivers being on payroll of private party, one off-incident can make things go out of control. Congested roads mean that large diameter city-bus fight for space with auto rickshaws and private vehicles, often giving rise to acrimonious situations. Despite breaking new grounds in early stages, operators have some complaints. No dynamic pricing or variable frequency of buses is practiced which could maximize their revenue, possibly due to public backlash in first case and due to management difficulty in other. Condition of roads also leaves a lot to be desired and this is something entirely out of control of ICSTL. This has become a crucial handicap on some of the routes. Then private bidders get no first right while bidding for new routes and there are regular demands by various interest groups for new buses or routes without realizing that there were negative revenue sharing bids for some routes by operators in the beginning and even today few routes have zero revenue sharing contract. Taking city buses to every nook and corner of city would not be easy because of congested roads, opposition from private service providers and most importantly, bidding revenue by bus operators and advertiser both would be low as was experienced while bidding for suburban routes.

14. WAY AHEAD

Encouraged by the success of the city transport services, the ICTSL is fast tracking the provision of quicker and more convenient services of international standard using the BRTS. This Rs 900 crore (US $ 200 Mn.) project envisages construction of speedways dedicated for buses, offering the commuters a safe and rapid mode of conveyance along arterial routes. The peripheral routes will continue to be serviced by the existing ICTSL city buses, thus providing an integrated and economic solution to the transport needs of citizens. Further, the system is expected to provide much required incentive to the private vehicle owners to switch to the more convenient BRTS Buses. A pilot project on a priority corridor from Niranjanpur Square which is on the outskirts of Rajiv Gandhi Square (AB Road) is under execution.

The city is also developing River Side Bus Rapid Transit Corridor to decongest the city centre. While Indore has many North-South and East-West corridors, there is no Central Corridor which is vital to the transportation needs of the city since there are many trips made to this sector—in fact far exceeding the other corridors. Hence, to address this need, the River Side Corridor shall be developed by channelizing the river and streamlining its flow. This will provide open bank area to be raised and developed as bus lanes, pedestrian paths, and cycle lanes with a huge green buffer. This exclusive BRT and Non- Motorized Vehicle (NMV) route shall greatly decongest the traffic in the core central zone and encourage people to use the mass transportation system. Further, this will reduce the level of pollution in the central zone of the city.

15. REFERENCE & ACKNOWLEDGMENTS

Mr. Chandramouli Shukla, Ex CEO, ICTSL
Mr. Vivek Aggarwal, District Magistrate, Indore
Mr. Madhav Pai, Embarq, India
Ms. Prajna Rao, Embarq, India
Mr. Abhijeet Atray, Technical Consultant
Brochure ICTSL, Indore, India
Indore city- A Novel experience in Urban Transport by Anand Sharma & Anshul Gupta
Paper on modern transportation at Veer Jijamata Institute of Technology, Mumbai.
**PAPER TITLE**

'Overcoming Urban Mobility Challenges by Changing Individual Travel Behaviours'

**TRACK**

D.2 Urban Mobility Management

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<th>COUNTRY</th>
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<tbody>
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**KEYWORDS:**

Open platform, oneM2M, Multi-modal integration, Travel behaviour

**ABSTRACT:**

Transport and local authorities are being encouraged to achieve more from their networks and make them ‘smarter’ to deliver reduced congestion and modal shift, but is this possible in the prevailing economic climate? Review of the oneTRANSPORT concept, which has emerged from Innovate UK’s Integrated Transport initiative suggests the answer is a resounding ‘yes’.

oneTRANSPORT is an open, standardised, marketplace solution that can enable a transport industry revolution like that experienced by the telecoms industry over the past two decades. It represents a scalable, exportable marketplace for transport data, enabling SMEs, incumbent suppliers and new players to engage in delivering enhanced services, facilitating new business models, service innovation and new investment into the transport marketplace.

oneTRANSPORT enables multimodal transport information to be published by data owners (e.g. transport authorities and new third parties) and accessed nationally by transport authorities, application developers and others. This allows delivery of a superior travel experience as well as generation of new revenues, in-journey travel optimisation and added value services that the real system ‘user’ - the traveller - desires and finds beneficial. It represents the next stage in transport mobility evolution enabled by the opening up of currently closed data assets.

The approach reflects the trend of transport authorities migrating capabilities to the cloud. Government policy on Open Data is making this future vision possible. Embracing this approach will enable the industry to set its own future direction of travel; inaction will result in that data being used by others. By operating at the Service Enablement level, it uses existing and new data assets to create competitive markets in applications, analytics and service provision (Data-as-a-Service and Platform-as-a-Service), offering a route to market growth for existing suppliers of ITS management solutions, of sensors and of software.

- A fairer open market place to access transport data and transport analytics, and
- Lower cost entry model for transport authorities to access creative travel services
Influencing Travel Behaviour to Reduce Congestion and Converge Transport Demand and Capacity Through An Open Ecosystem

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1 Introduction

Although transport networks have been around for thousands of years their purpose has not really changed; with the primary aim being to get from an origin to a destination in the most efficient way possible. In this context and depending on whether it is an end-user (traveler) or a transport authority, efficient can include, cost, time, condition of transported goods, safety and reduced impact to the environment. There have been many different modes of transport since the early days of travel with each providing a specific function and user.

Over time it has been the creation of wealth and prosperity, and the desire to travel that has driven the vast increase in our transport networks and the vehicles that use them. One thing is very clear; transport of the future will have to be different to the near term predictions of today. For example, the continued move towards urbanization will reduce the available space in our cities and increase the demand for travel services (Arup et al 2014).

- Global urban population is growing at two people per second, adding 172,800 new city-dwellers each day
- 2/3 of the world will live in cities by 2050
- Africa is seen as the most rapidly urbanising region on the planet

Demographic and socio-economic shifts will result in a new global order. These changes will affect the way we travel and the need to travel (Arup et al 2014).

- Increase from 11% to 20% of the world’s population over 60 years old
- 9.5 billion by 2050
- 50% of population moved into middle class

The Intelligent Transport Systems (ITS) industry has been deploying technology and providing travel benefits to users for more than 30 years; but has found it difficult to provide the right information, at the right time and in the right place. The lack of consistent and accurate messaging has negatively impacted the reputation of transport authorities and promoted a culture whereby some users often ignore travel information provided in this way. Surprisingly travellers seem to trust travel information that they purchase through the private sector ‘apps’ when in many cases some of the raw data sources are the same. Over the last 40 years ITS has constrained its own potential through proprietary products, point solutions and a silo mentality, making it difficult for new ideas and innovation to emerge. There is a fine balance between opening up the market to provide additional resource, innovation and ideas, but also maintaining and allowing Intellectual Property Rights (IPR) and previous industry investment to be part of our future solutions. The challenge is how to protect a company’s IPR but at the same time open up these innovations to a wider industry to enhance future ITS services to deliver enhanced transport mobility.

Data sharing within the transport sector and useful interpretation of that data has been impeded by the use of bespoke products and closed data sources preventing the established ‘app’ development community from being able to realise the full potential from the seemingly excess of transport data collected each day. However the quantities of data collected today are insignificant compared to the trillions of data sets expected through the implementation of the Internet of Things (IoT). The opening up and sharing of data can create risks from data security and privacy of data and whilst early methods to anonymize data have been successful there is much more to be done in this space.

Developments such as Urban Traffic Management and Control (UTMC) revolutionized traffic data sharing and exchange in the early 2000s but has not fully engaged the data silos across other transport modes. Siloed development has produced only modest enhancement unlike trends of other sectors. (see Figure 1).
This results in minimal economies of scale, expensive proprietary solutions, a high degree of vendor lock-in, complex purchasing decisions by busy and unskilled customers (Sir Nick Partridge 2014), limited cross-region interoperability between authorities and minimal availability of data to the external community. This situation parallels other sectors, for example the telecommunications sector 20 years ago; an era of relative high cost and inefficiency, unlike today where billions of subscribers, business and personal make use of the ‘digital age’. The highly fragmented nature of existing data sources makes it almost impossible for an open application ecosystem with all its benefits to emerge in any meaningful way. However the public release of the oneM2M global standard in August 2014 (oneM2M et al 2014) offers a unique opportunity to kick-start the slow moving ITS industry, overcoming hindrances that have stood in the way of integrated transport. OneM2M provides a solution to this problem in its core value proposition by defining a standardized horizontal service layer to expose data sources.

The market into which oneTRANSPORT plays may be broadly characterized as the Machine-to-Machine (M2M) Communication in the Smart Cities and Public Transport arena. The most pertinent sub category of this market that this solution plays is the traffic management category. Research forecasts the ‘smart cities’ and ‘public transport’ sectors as a whole will generate over 500 million M2M connections by 2020 from around 59 million in 2011. Traffic Management will account for the lion’s share of those connections throughout the forecast period, growing to 446 million in 2020 (Machina Research 2012).

2 Feasibility Study

In October 2013 the UK Technology Strategy Board (TSB) issued a competition call in the area of ‘Integrated Transport: In-Field Solutions’. This call was designed in two parts consisting of, a feasibility study, the output of which would later serve the creation of a second call for proposals for a large scale field trial. In January, 2014 the consortium consisting of InterDigital Europe (Lead Partner and technology platform provider), Buckinghamshire County Council (primary stakeholder), ARUP (transport industry specialists), Worldsensing (transport sensor specialists) and Traak Systems (transport analytics specialists) were awarded a grant by the TSB in support of their feasibility project proposal ‘oneM2M based open ecosystem for Transport Modal Shift’ henceforth referred to as oneTRANSPORT.

The RfP sought solutions to address the immediate, and anticipated future challenges facing the transport industry (e.g. congestion, shrinking budgets, etc.). The key features of the Feasibility Study included:

- Cross-Industry Research and Education
- Internal Use Case Workshops
- External Transport Authority Workshops
- Industry Engagement
- Technology Architecture
- Business Case Modelling
The economic nature of the challenge that oneTRANSPORT attempts to address is common at local, national and international levels and therefore has a wide client audience from transport operators and transport authorities. The seriousness of the problem in the UK has been outlined in reports over the last decade:

- The estimated cost to the UK economy attributable to road traffic congestion as £7-8bn (Eddington 2006).
- Lost Customer Hours, not included in the above figure, were estimated in a recent report commissioned by the TSB as £80bn (Technology Strategy Board 2013).

Globally this represents a massive opportunity, which the transport industry is well placed to address. Solutions which embrace global standards and open up transport data have potential to unleash latent demand for new ITS products and services and create revenue streams to support the opening up of data.

3 Study Approach

The study approach brought together experts from two distinct industries, transport and mobile communications that began with extensive mutual education, involving an internal workshop, regular meetings and attendance at an international traffic industry event in Amsterdam in 2014 to re-affirm views and challenge the disparate approaches promoted within the transport arena. The main aspects are described below:

3.1 Review, explore & analyse the UK (and global) transport ecosystem

The challenge from city mayors and transport authorities to the industry has been to provide the tools to deliver significantly enhanced user travel services that have a direct impact to route, mode and time of day travel choices, thereby reducing peak demand and associated congestion, air pollution and dissatisfied citizens. This vision is neither new nor unexpected; however the challenge was to establish the appetite at the grass-roots for improvements and to identify the barriers that prevent this paradigm shift to transport integration. This was achieved by (1) learning lessons from history, via desktop study and interview, (2) engaging key stakeholders to help validate the problem and solution concepts, and (3) assessing the industry opportunities and barriers to an open data, global standard solution.

Based on engagement activities, there is clear recognition amongst all stakeholder groups of the emergence of a more profound open data market and the potential transport network benefits that may be derived from releasing the data held by central government, local government and private authorities. This is being driven by the initiatives of government, non-governmental organisations and commercial enterprises, and the rapid evolution of the smartphone as a tool for managing everyday life. There is also a common appreciation that government and transport authorities cannot afford to make all the transport network infrastructure improvements that are needed to address current congestion problems and those that will be generated from growth in, for example, car usage and housing development. Accordingly, there is a clear acknowledgement that ‘we must do something different’ to make better use of the existing network, the data it produces and providing services to allow greater choice.

3.2 Define the system architecture & its evolution

Significant investment has been made in transport technologies which has, and still, provides direct and indirect benefits through reduced traffic signal optimisation, stop-starts in cities, unified speed and flow on motorways etc. In defining a system architecture that has credibility and business potential, fundamental requirements are:

- Legacy systems can be retained and integrated at least until the end of their project life cycle.
- A national, and international solution to attract investment and ‘pull’ from the private sector.
- A simple and future-proofed migration path to the Internet of Things (IoT).

By introducing a new layer of functionality, that is ‘service enablement’ to complement traditional and legacy technologies such as SCOOT (Split Cycle Offset Optimization Technique), SCATS (Sydney Coordinated Adaptive Traffic System and UTMC (Urban Traffic Management & Control), oneTRANSPORT will open up transport data assets in in a way that has never been done before, going beyond simply Open Data to complete the value chain to the ‘citizen end user’ and so opening up a new level of possibilities in transport application experience that will allow congestion to be addressed on a national scale and monetizable benefits to be delivered. The system architecture for oneTRANSPORT utilises the standard for oneM2M (see Figure 2) which allows:

- Interface with and leverage existing legacy transport infrastructures
- Support for existing transport sensor systems & services and will readily enable new ones
- Enable a new market in national, local and private authority transport data.
- Enable independent third party provision of new transport services for the public e.g. app development.
- Support to accelerate implementation of government Open Data initiatives.
The architecture is ‘evolutionary as opposed to revolutionary’, that is it does not require a ‘clean slate’ investment by Transport/Local Authorities, rather allowing authorities to adopt at their own pace when they are able and ready. Critically in today’s restricted budgets it reduces the need to invest in significant capital IT infrastructure, seeking instead to procure and enable services.

3.3 Study the business aspects of oneTRANSPORT

The ‘Big Picture’ context, including technology advances and the Internet of Things (IoT) are possibilities of the future that must be considered although cannot be the starting point for real-time travel services in the near future. What has been identified is a repeatable and portable exemplary application that could deliver tangible impact to the transport problems of Buckinghamshire, Northamptonshire, Hertfordshire and Oxfordshire in the UK by reaching a target audience of over 3 million users. Demonstrating that similar solutions can be transferred to other towns and cities, both nationally and internationally. A key feature of the service approach is that smaller towns and authorities can access the facilities of much larger cities, such as London, New York, Istanbul and Paris. Therefore, in assessing the business aspects of such a solution the immediate focus has been to establish potential benefits and money flows from a trial based around Buckinghamshire and neighbouring counties, with scaling to regions and then nationally across the UK.

Three strands have been assessed:

- Business model options and benefits across the value chain, looking at potential new revenues into the ITS ecosystem have been explored - Platform-as-a-Service (PaaS) and the Platform-and-Data-as-a-Service (DaaS).
- Modelling of investment and money flows was undertaken to financially analyse the business and end user benefits.
- Opening data in an anonymous manner and maintaining security of that data.

The role of all players in the value chain has been considered and the results of the business assessment has confirmed financial viability of such a solution, evaluating both direct and indirect (non-cashable) benefits. Within the assessment it has been assumed that Buckinghamshire County Council will initially own and operate the oneTRANSPORT platform, offering PaaS hosting to adjacent counties. Over time it is assumed that Platform ownership will likely evolve and could potentially be outsourced, with other platform operators and a competitive market emerging.

4. What are the challenges to providing integrated travel services?

Most of the transport authorities in the UK and indeed internationally have a vision for truly integrated travel services that make the most of public transport and provide meaningful travel data to private car users in an attempt to change their attitudes and behaviours to travel choice. It is not just the transport authorities that have such a vision, it is suggested that all travel users expect better travel information, whether this is pre-trip or on-trip. With the emergence of smartphones to provide ‘on-the-move’ services and the explosion in ‘app development’ to make use of more easily available data, the public at large expect better travel services. The Feasibility Study has considered the many
challenges facing a successful oneTRANSPORT. Some of the challenges are being addressed ahead of the trial whilst others will be demonstrated during the trial. The oneTRANSPORT initiative has identified five key risks:

- Legacy system providers and customers not realising that oneTRANSPORT is an additional layer of functionality not currently provided and therefore not a competing solution.
- Transport authorities not having the resources to unlock existing data sources.
- oneTRANSPORT needs sufficient and complete data to make it worthwhile for subscribers
- oneTRANSPORT is multi-modal, but to suit the issues of Buckinghamshire County Council the exemplar application is strongly road focused and could give the wrong impression.
- Acceptance that the customer is the transport users, not the transport authorities

Traditionally traffic and transport technology systems have been provided to a limited customer base of transport authorities, private transport providers and national authorities. The model has been to provide systems and infrastructure, maintenance and sometimes operational services with refresh and upgrades provided throughout the life of the systems. Through the development of a data broker model (see Figure 3), and opening up the siloed data the emphasis changes from a small number of customers (transport authorities) to a much larger customer base for personal travel services, potentially increased by a factor of 100,000. This larger customer base provides a business opportunity for the app community.

Figure 3: oneTRANSPORT data model

5 Conclusions and Next Steps

The Study has identified an approach for delivery and exploitation that focuses on congestion relief through the application of predictive analytics and enhanced in-field sensors onto the oneTRANSPORT platform. To demonstrate the identified benefits for the UK, the in-field trial is predicated on achieving nine objectives:

a) Avoiding proprietary systems – to reduce the risk of downstream vendor lock-in.
b) Using globally-standardised technology (i.e. not just UK or Europe) - to open up the global market.
c) Supporting multiple existing infrastructures, so it can operate across diverse legacy systems
d) Involving multiple adjacent Transport Authorities - so it can demonstrate the above.
e) Delivering new sources of revenues into the transport ecosystem - so that UK local transport authorities find it (at minimum) cash neutral and hence rapidly adopt it.
f) Encouraging transport authorities to open up their transport data by creating new markets for them.
g) Encouraging solutions that facilitate new, open, competitive markets – to create opportunities for all participants
h) Employing an open, standardised, interface for new transport sensors – to support and make use of data from future IoT sensors that will be deployed outside of transport (future proofing) and to encourage interface standardisation (lower costs) amongst transport sensor and system suppliers.
i) Measuring the modal shift effectiveness of such services, to allow their comparison and improvement.
The Feasibility Study stage has been completed and preparations are being made to proceed with the in-field trial. There have been some key lessons learnt during the Feasibility Study which include expanding the data sources through engaging with additional transport authorities and understanding how to cleanse and anonymize data.

7 Summary

The fragmented nature of transport management directly impacts the issue of traffic congestion. The project explored the feasibility of a world’s first ITS platform based on the emerging international standard oneM2M. State-of-the-art behavioural and predictive analytics will process an array of transport relevant data, enabling prescriptive personalised transport guidance to end users via a smartphone application, to ‘nudge’ behavioural choices. This approach is scalable, standardised, and non-proprietary and can ignite the open data developer community. It offers compelling benefits for Local Authorities with strong or poor infrastructure, with realistic potential for national and global adoption. The Study focussed on specific system design, business framework aspects and planning for an in-field trial in Buckinghamshire.

Whilst existing suppliers of proprietary solutions might initially feel threatened by such a change, history in other markets shows that open standards drive economies of scale and market growth which will offer such players significant opportunities (cf. telecoms). This approach offers the opportunity to transform Intelligent Transport Systems from what is today a highly geographically fragmented marketplace into one where new economies of scale are possible, new actors, investment and business models are unleashed in a way that parallels the transformation seen in the telecommunications industry over the past two decades. The approach is open, scalable and exportable.

An exciting and rewarding activity of the Feasibility Study has been the engagement with industry, users and transport authorities (data custodians). As well as workshops, discussions, meetings and follow-up dialogue have been held with many parties in the transport management ecosystem. These have included Local Authorities, transport management organisations and operators, the UK’s UTMC Development Group (UDG), UTMC suppliers, the Transport KTN, the Open Data Institute, application developers and others. There has been widespread interest in the oneTRANSPORT approach, with many discussions on-going, including preliminary discussions for other commercial and R&D opportunities in the UK and internationally.

In addition to its accuracy and completeness the Feasibility Study outputs are being evaluated to assess the potential for supporting UK industry development of products and services both in the UK and internationally. The key outputs are:

- Ecosystem Review and Analysis
- oneTRANSPORT solution overview
- System Architecture and Evolution
- Exploitation Plan

Acknowledgements

The Technology Strategy Board (TSB) for supporting the Feasibility Study and TSB staff for providing monitoring support in meeting our obligations. The KTN Transport Community, formerly the Transport KTN, for assisting in organising and engaging in industry workshops. ITS-UK for assisting in supporting on behalf of members to the workshops.

Participants at workshops, meetings and interviews are providing the time and effort to challenge the concepts of oneTRANSPORT and offer suggestions.

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Mobility Management using Rapid Transit Systems in Jamaica

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KEYWORDS:
Stated Preference, Mode Choice Analysis, Bus Rapid Transit, Rail Transit, Jamaica

ABSTRACT:
Transportation is the largest consumer of fuel in Jamaica accounting for 22,940 barrels of oil per day and overall US$1.6 billion in foreign exchange (2010). This is directly related to infrastructure supply, government costs, vehicle supply and personal mobility where there is low automobile ownership among the general population and unregulated public transport competing against government owned public transport that has been operating at a loss since its inception.

Focusing on the role of rapid transit systems in the Kingston Metropolitan Transport Region (KMTR), a stated preference (SP) experiment was conducted in Spanish Town and Portmore. Using 200 respondents, a mode choice analysis was conducted to forecast travel demand analysis for bus rapid (BRT) and rail transits. Binary logit models were constructed for each urban area and utility functions estimated for the perceived value associated with primary attributes travel cost, journey time and service frequency, and the effect of socio-demographic factors.

The SP experiment qualifies the introduction of a bus rapid transit system for both townships. However, attracting existing users will require an improvement in cost, comfort and reliability of service and unless there is a change in the perception of public transport, then there is little hope of attracting new users. The introduction of a rapid transit system in the KMTR is not to effect a modal shift but to facilitate efficient movement along the transport network, to address the issue of traffic congestion. The success of this system may then lead to secondary benefits of capturing private car users.
Introduction

Transport provides the linkage between land uses that are spatially and temporally segregated such as commercial, residential, social and recreational activities, and is generated by the desires of people to move and their need for goods (Khisty and Kent, 1998; de Dios and Willumsen, 2001). To satisfy optimally mobility needs subjected to increased demand, resource and impact constraints, the transportation system requires systematic and continuous planning functions including; forecasting travel demand, improving transport service provision, and assessing the adverse effects of transportation systems (Khisty and Kent, 1998). However, these planning functions are largely conducted reactively and are more demand responsive, especially in developing countries which are limited in their capacity to routinely investigate the impacts of and on transport services.

In the context of Jamaica, a developing nation with a population of 2,698,800 at December 2009, the country is burdened by growing urban populations, increasing motorisation and rising passenger and vehicle kilometres travelled per capita that is creating a huge infrastructure backlog and escalating environmental concerns, placing constraints on economic development and even affecting cross-sectoral linkages such as poverty and health. Following a large schematic residential development in the 1960s located in south-eastern St. Catherine called Portmore, urban sprawl outside the Jamaica’s capital city Kingston took on vast proportions as the expansion of commercial and financial services within Kingston and St Andrew (KSA) created employment and education opportunities which caused mass rural to urban migration. Construction of dwelling units in Portmore of 5,100 in 1971, 93,800 in 1991 increased to approximately 161,658 in 2001 which had to be expanded to include Spanish Town to accommodate the growing urban population (STATIN, 2010).

These areas evolved into large suburban cities with a high dependence on KSA for employment, education and retail services, while much of the labour force resided in these suburban areas. Spatial fragmentation beyond the city limits resulted in increased mobility needs and the Transport Ministry, faced with the challenge of extending its services had to produce a coordinated regional transport system. KSA was expanded to form the Kingston Metropolitan Region (KMR) and the development of a transport region called the Kingston Metropolitan Transport Region (KMTR). The continued housing development in Spanish Town and Portmore resulted in large volumes of traffic travelling into KSA daily as housing affordability and the relatively short distance made Spanish Town and Portmore attractive alternatives to living in Kingston.

Public passenger transport capacity in the KMTR had not kept pace with the housing growth as investment in the transportation system was limited by, inter alia, inadequate government funding and a lack of interest by private sector investors. The bus service which had been operating at a loss because of a decline in ridership and farebox receipts was deregulated, in hope of producing a more efficient public transport system through fare reduction and increased services, resulting in a ‘free-for-all’ service (Cervero and Golub, 2007; TA, 2008). As a consequence, the public transport sector was overrun with private franchise holders controlled by absentee investors, who did not operate vehicles but merely acted as an intermediary between the Government and public transport operators (TA, 2008). In 1989 the Government rescinded the route sub-franchising with individual operators with a return to regulated public transport system and an exclusive licensing system was created to be operated by a nationally owned operator known as Jamaica Urban Transit Company (JUTC) on fixed routes and scheduling (TA, 2008). However, efforts to contain the system by creating a public monopoly failed, because of high cost overruns, an unreliable service and lack of vehicle capacity which resulted in an un-serviced demand and the birth of an informal public transport sector referred to as ‘illegal robots’ (Cervero and Golub, 2007). This coupled with an increase in private motor vehicle ownership resulted in traffic choked corridors from the West going into the KMA daily, especially during peak periods (see Cervero and Golub, 2007). By 2006 the two main corridors which transport traffic into the city from these areas were operating 170 percent above capacity. The Nelson Mandela Highway and Portmore Causeway were so congested that travel time was twice the average journey time (NWA, 2007). The transport deficiencies of the KMTR threatened to undermine realization of some of the expected benefits of critical infrastructure developments, such as the Highway 2000 (H2K) project. Highway 2000 is an approximately 250 km long tolled highway which links Kingston to Montego Bay and Ocho Rios, providing improved access to urban, industrial and commercial centres such as Portmore, Spanish Town, May Pen, Old Harbour and Mandeville. An assessment of the public transportation system by Transport Authority (TA) (2008) concluded that in order to address the challenges of global warming, traffic
congestion, the increasing national import oil bill, the reliance on motorcars needs to be curtailed. The study suggests the future for public transport lies in rapid mass transit such as rail and bus rapid transit (BRT) and that such a move has to be ‘sooner than later’ as Jamaicans are becoming more car dependent with each passing year.

**Literature Review**

Touted as one of the most important and effective strategies of sustainability mobility (Victorian Competition and Efficiency Commission, 2006), the postulates for improving public transport by many researchers (Currie and Wallis, 2008; Currie and Hensher, 2008) has failed at capturing levels of public transport use that is sustainable or called for in policy statements (Stopher, 2004). Through travel behaviour research, analysts have attempted to gain insight into the factors that affects mode choice, both endogenous and exogenous, to determine why public transport has been unable to capture larger market shares globally. Beirao and Cabral (2007) state that since the car is the most attractive mode, instigating and influencing a modal shift will require addressing the attributes that has crowned the car as king of the road – convenience, speed, comfort and individual freedom. Although these attributes are considered intangible and not easily measured, Jensen (1999), Hagman (2003) and Anable (2005) attempted to measure these abstract attributes by classifying car drivers or travellers in mobility groups. Paulley *et al.* (2006) considered the determinants of demand for public transport in the UK such as fares, quality of service, income and car ownership. They suggested that gains made in public transport are negated by similar but higher effects on car ownership. For example, while fare elasticity may increase over time for public transport, the same remains true for car ownership. The result of these studies indicates that improvements to public transport need to be made if it is to be an attractive alternative to the car. Investment decisions will have to be approached rationally with regard to economic, social, technical and environmental considerations, as well as making it more market-oriented and competitive (Thompson and Schoefield, 2007). Equally important too, is the type of public transport required to effectively meet the demand (Bates *et al.*, 2001; Currie and Wallis, 2007). A shift from heavy to light rail and more recently to bus-based systems has much of the debate on public transport between Bus Rapid Transit (BRT) systems and rail systems. Notable comparative studies include Stone *et al.* (1992), Kain (1988), Litman (2003); (2004); (2005); (2007), Hensher and Waters (1994), Hensher (2007) and Ben-Akiva and Morikawa, (2002).

According to Ben-Akiva and Morikawa (2002) one of the first comparison’s was Vuchic’s study of Lindenwold Line and Shirley Highway where, Vuchic states they are two different types of services and therefore should not be compared, although he concluded most of the attributes favoured rail (Vuchic and Stranger, 1973 in Ben-Akiva and Morikawa, 2002). Similarly, Hensher and Waters (1994) feels any comparison has to be qualified since most rail services are for longer distances while buses have a greater scope for attracting passengers. They suggests this may be the reason why much of the earlier debates were centred on costs and benefits, patronage and cultural preferences (Pickrell, 1984; Kain, 1988; Richmond, 1991; and Stone *et al.* 1992) rather than legislative changes which support bus transit systems, impacts on land use and the need to identify and inform the public of the fundamental differences between traditional bus systems and bus priority systems.

However, Litman (2004; 2005; 2007) who has conducted a number of studies on the benefits of rail systems, opines that rail transit is a sound investment as a congestion reduction strategy when all economic costs are considered. In his most recent paper, Litman (2007) cites a number of examples where subsequent to the implementation of rail transit, there was a decline in traffic congestion, significantly lower commute travel times or per capita congestion did not increase relative to population growth. He notes, from an operational perspective rail costs are lower and easier to recover especially when alternative fuels, seating space and capacity are considered. From a household perspective, rail provides a positive return on investment and economically stimulates growth through employment and business productivity. Other proponents of rail transit consider it a better investment for public transport since it operates in its own right of way and on a single mode infrastructure (Vuchic, 1991; Garrett and Castelazo, 2004). However, Kain (1988) contend that when buses operate on exclusive right of ways or guided bus-ways they are able to attain speeds equal to or higher than light rail. In light of this, advocates of BRT claim that BRT and rail can be compared like for like in the following areas: infrastructure provision (guided busway and rail track); carrying or vehicle capacity; and, service capacity. Despite this, rail is thought to be superior to bus-based systems when factors such as comfort and reliability are included in the comparison, notwithstanding the fact that buses are able to cover a denser network (Ben-Akiva and Morikawa, 2002). Ben-Akiva and Morikawa conducted a qualitative
study to determine if significant preferences exist for bus or rail by examining two areas in the US – Boston and Washington DC. They assert that the two transit systems are equivalent when qualitative measures such as travel time and cost are equal, but rail is preferred when considering service quality characteristics. Similarly, Tirachini et al., (2010) did a quantitative study of bus and rail for three different objectives: total cost minimisation, profit maximisation and welfare maximisation. They found that when BRT maximum capacity is utilised, the only advantage for rail is value of travel time savings since rails are faster. However, when attributes such as crowding and comfort (welfare) are introduced then rail is the more cost effective of the two modes.

However, Hensher (2007) makes a case for BRT by comparing operating costs, service capacity and vehicle capacity in Australia and the US. Hensher states an audit conducted by the USA General Accounting Office (2001) found that cost per mile for LRT compared to BRT in its own lane was 260 percent more. Additionally, BRT is able to transport the same amount of passengers for 4-20 times less than the typical cost for LRT and 10-100 times less than a heavy rail system. The average maintenance and operating costs per rider on Pittsburgh’s BRT for example is lower than rail systems in Buffalo, Pittsburgh, San Diego and Sacramento averaged.

Approaches to Mode Choice Analysis

Approaches to modelling mode choice typically involve statistical analysis of travel behaviour and cross-sectional data which involves the estimation of disaggregate choice models (Ben-Akiva and Lerman, 1985; Ben-Akiva and Morikawa, 2002; Louviere et al., 2000). These analytical techniques are generally classified into two broad categories namely, revealed preference (RP) and stated preference (SP) methods. RP data typically relies on observed choices of travellers, while SP data relies on travellers’ preferences for hypothetical choice alternatives. RP and SP approaches have been widely used in studying preferences to produce empirical models for predicting travel behaviour. However, while both techniques are reliable methods of data collection, there is a plethora of literature which identifies the limitation of RP methods in discrete choice experiments (Louviere and Woodworth, 1983; Hensher, et al., 2005; Prioni and Hensher, 2002; Carson et al., 1994). It is because of the inherent weakness of RP data that SP data gained popularity in transport studies in the 1980s (Bates, 1988; Ortuzar and Willumsen, 2001; Louviere et al., 2000).

Initially, Kroes and Sheldon (1988) identified four limitations of RP data: multi-collinearity between explanatory variables, the inability to forecast for conditions that do not yet exist; the inability to determine causal relationship of secondary or qualitative variables; and, model mis-specification which RP data cannot account for. Louviere et al. (2000) further added two additional factors namely, the relatively large sample size required to accurately model behaviour and the introduction of new variables which requires studies on current choices. Ortuzar and Willumsen (2001) state these limitations would be surmounted if real-life choices could be observed, rather than obtaining data on what individuals say they do. But RP data has high reliability and face validity since they are real choices made by individuals (Louviere et al., 2000) and it embodies any constraints faced within real markets and thus is especially useful short-term forecasting.

On the other hand, SP techniques are usually constrained when predicting real market conditions but allow attribute trade-off information in hypothetical scenarios, thus creating more robust model estimates than RP data (Swait, 1994). The fact that a wider range of attributes, both qualitative and quantitative can be built into experiments has made SP methods the dominant source of data used in estimating behavioural responses (Rose et al. 2009; Bliemer et al. 2009). The popularity of SP methods is such that it has been applied across a range of disciplines including transportation, health, marketing, environmental science among others. It is not without its share of criticisms though and early studies of applying SP data in transport produced unreliable estimates (see Ortuzar, 1980; Fowkes and Preston, 1991) which required improving SP techniques. In fact, SP data has been questioned on a number of grounds. A study paper presented by Bradley and Daly (1994) questioned the validity of SP data because they found surveys were likely to generate systemic bias in estimated model parameters which compromises the reliability of any forecast made consequently. Walker et al. (2002) modelled tenants’ choices in public rented sector and mentioned affirmation bias where respondents’ made choices which were consistent with study objectives. Street and Burgess (2007) notes two additional biases called rationalisation bias where respondents attempt to justify current behaviour and respondents efforts at influencing the outcome of the survey termed strategic or policy response bias. There is therefore some amount of uncertainty in SP responses as elicited preferences may
differ from real life choices (Ben-Akiva and Lerman, 1985; Louviere et al. 2000). However, the nature of SP techniques has improved considerably since the 1980s, with theoretical and practical advancements made in survey design, presentation and statistical analysis.

The foundation for any SP experiment is an experimental design (Hensher et al. 2005). Traditionally, orthogonal fractional factorial designs were employed in generating SP experiments. Orthogonal designs ensure that the attributes in a design are independent of each other or uncorrelated and so the effects of each variable can be determined separately. More importantly, orthogonality implies the coefficients will have minimum variance with exceptions (Kuhfeld et al., 1994). However, whilst orthogonality allows for the effects to be estimated independently, the statistical efficiency has been questioned by researchers (see Kuhfeld et al., 1994; Huber and Zwerina, 1996). In constructing SP experiments it is important that attribute and levels are considered carefully so that no alternative is preferred over all the alternatives present. If a dominant alternative exists, then the data is statistically useless since respondents are unlikely to make trade-offs between alternatives present (Street and Burgess, 2007). Orthogonal designs disregard this aspect of SP experiments resulting in limited information obtained about the parameters of the attributes (Hensher and Rose, 2007). However, the popularity of the design within the transport literature (see Bliemer et al., 2009) has indicated that practical reliable estimates can be obtained compared with other designs that are largely theoretical in nature.

Analysis of SP Data

The aim of analysing SP data is to determine parameter estimates or the weight associated with each parameter that contributes to the overall utility of an option. Estimation of choice models take many forms such logit, mixed logit, probit, dogit and the elimination-by-aspects model (McFadden, 1974; Train, 2003). These models can be broken down in binary, trinomial or multinomial models depending on the number of alternatives under investigation. However, they share three similar properties:

- The set of alternatives must be exhausted;
- The set of alternatives must be mutually exclusive;
- The set must contain a finite number of alternatives.

The models differ however based on derivation of random or unobserved factors known as the stochastic or error component (\(\varepsilon\)). This general derivation is similar for all the models but of issue is the distribution assumed of unobserved factors for each model (Train, 2003). The logit model is the simplest and therefore more feasible in complex choice situations (Ben-Akiva and Lerman, 1985) but, Train (2003) notes three main limitations: the Independent and Identically Distributed (IID) assumption limits its applicability in cases of substitution; random tastes variation cannot be captured; and, it cannot be used with multi-dimensional data when correlation exists between unobserved factors. Yet it is the most commonly used DCM in the transport literature proposed by Hensher & Prioni, 2002; Hensher et al., 2003; Ben-Akiva and Morikawa, 2002; O’Fallon et al., 2007. Probit models address all the assumptions of logit models but require that the observed components are jointly normally distributed. Its main advantage though, is the ability handle correlations over alternatives and time but it has a closed form and thus must be expressed as an integer (Ben-Akiva and Lerman, 1985). The dogit model was derived by Gaudry and Dagenais (1979) to overcome the IIA difficulty by retaining the simplicity of the logit format but committing to the IIA restrictions. Mixed logits are becoming increasingly popular as they allow the unobserved factors to follow any distribution. The defining characteristic of a mixed logit is the ability to break down the stochastic component so that correlations which can follow any distribution, and IID extreme values can be separated (Train, 2003). Wrigley (1982) comparisons of the various models concluded that the correlation of variables is not as significant as initially feared and Park (2009) states improvements in computational power and the development of new algorithms proves little difference between models. The choice of model is therefore dependent on familiarity and the nature of the choice scenario rather than theoretical and interpretive aspects.

Survey Methods

There has never been a Stated Preference (SP) experiment for transport related services conducted in Jamaica. Therefore, both primary and secondary data sources were explored to collect information necessary for discrete choice analysis. The Ministry of Transport and Works (MTW) through its Agencies, collects data for monitoring purposes. Relevant to this study, average daily traffic (ADT), vehicle turning movement
counts, public transport ridership and public passenger vehicle counts were collected through surveys and automatic counters. These secondary data sources were examined to determine any trends in travel and to identify factors that affect travel behaviour. This formed the basis for collecting primary data and aided in the design, administration and analysis of stated preference surveys.

In determining the most important attributes, a literature review was conducted on SP experiments with a focus on mode choice and travel behaviour. In order to capture first whether a preference exists between public transport and private car, and to reduce the cognitive load and thereby reduce respondents’ burden during survey administration, it was decided to include two SP experiments in the survey. The first experiment would establish whether respondents are willing to use PT by employing a combination of policy measures. The second experiment was a choice between two proposed modes of transport through a combination of three main attributes namely, journey time, travel cost and service frequency. This was done in hope of keeping the surveys relatively simple and easily understood.

The survey was divided into five sections: the first and second sections were designed to elicit information regarding travel habits and perceptions, attitudes and behaviour towards public transport. Sections three and four consisted of the two stated preference experiments designed to determine whether respondents were willing to use public transport if measures were introduced and their mode of choice. The first SP experiment consisted of policy instruments that could be regarded as deterrents to car use (sticks) and measures to encourage public transport use (carrots). The measures, toll charges, parking charges, improved service reliability and improved service frequency, each had three levels. The base level denoted by ‘no change/no charge’ represents the situation as it exists at the time of the survey. The second experiment consisted of the most relevant attributes of mode choice modelling: travel time, travel cost and service frequency. Respondents were asked to choose between two hypothetical public transport modes, a ‘no response’ option indicating no preference for either alternative and a ‘neither of these’ option to avoid forced choice selection of an unacceptable choice set, to increase realism. Each SP alternative represents a combination of three attributes varying on two levels. Three sets of combinations were produced to represent each study area which varies in distance and therefore travel times and cost. The L^4\text{2}\text{2} orthogonal design was used for the SP experiments consisting of four attributes, two levels and two alternatives. When designing experiments with more than one alternative they have to be sequentially designed for each alternative and then placed into choice sets or simultaneously designed and assigned choice sets. In this case a simultaneous design was generated for both alternatives which produced a full factorial design yielding 64 scenarios. However, in both experiments an orthogonal design was generated to produce 9 scenarios. The final section, included to supplement the choice data, is a set of contextual factors which are considered constraints or influences on mode choice. These include socio-demographic characteristics such as annual household income, age and gender, employment status, occupation group and vehicle availability.

Analysis of Data

In keeping with the objectives of the study, an overview of the sample was looked at by disaggregating the data collected by study area. Analysis of the data involved exploring socio-demographic characteristics, identifying travel behaviour trends, attitudinal data and estimating a binary logit model for each urban area. Survey data yielded 200 completed valid questionnaires equally divided between the two urban areas.

The analysis of SP data involved estimating a utility function for each city using a binary logit model to determine the choice of mode, parameter estimates and the effect of socio-demographic factors on choice.

The choice probability for the alternative BRT is given by:

\[
P_{BRT} = Pr(U_{BRTi} > U_{Raili})
\]

\[
= \frac{1}{1 + e^{\mu_{BRTi} - \mu_{Raili}}}
\]  

(Eq. 1)

\[
= \frac{e^{\mu_{BRTi}}}{e^{\mu_{BRTi}} + e^{\mu_{Raili}}}
\]  

(Eq. 2)

The corresponding utility function for the model for mode j takes the form:
\[ U_j = \beta_1 + \beta_1 \text{JourneyTime}_j + \beta_2 \text{TravelCost}_j + \beta_3 \text{ServiceFrequency}_j \]  
(Eq. 3)

Where the attributes journey time, travel cost and service frequency vary by mode.

An estimation of utility parameters and the statistical significance of these parameters was ascertained using the likelihood ratio test. This test assumes that, under the null hypothesis all coefficients (\( \beta \)) are zero for a likelihood function \( L_0 \). The likelihood ratio test uses the maximized value of the likelihood function for a full model with all the relevant attributes \( (L_\beta) \) over the maximised value of a null hypothesis \( (L_\theta) \) and is written as:

\[-2\log \left( \frac{L_\theta}{L_\beta} \right) = -2[\log(L_\theta) - \log(L_\beta)] = -2(L_\theta - L_\beta) \]  
(Eq. 4)

This test statistic distributed as a \( \chi^2 \) with \( k \) degrees of freedom. The other important statistics are Hosmer-Lemshow Goodness of Fit Test, Cox and Snell R squared and/or Nagelkerke R squared. These are similar to the \( R^2 \) in regression analysis and explain how well the data fits the model and is a useful summary of the quality of the model. Tables 1 and 2 show the results of the analysis for Portmore and Spanish Town respectively.

**Spanish Town**

The transport mode rail is defined as the reference category and parameters are set to zero, indicating all coefficients are interpreted in relation to this category. Table 1 displays the model results for Spanish Town with main effects only. The overall model goodness-of-fit, ranges from 0.564 (Hosmer and Lemshow), 0.685 (Cox and Snell) to 0.945 (Nagelkerke) with reference to Mcfadden’s R2 (greater than 0.4 is interpreted as good fit [Muller et al., 2008]). The log likelihood of 78.05, \( \chi^2 = 668.30 \) also indicates a good fit. The H0 can be rejected that all \( \beta \) are equal to zero, but not all parameters are statistically significant at the 95% confidence level. The estimates of the coefficients display the expected signs and relative values but there are clear differences regarding levels of travel cost, journey time and waiting time (waiting time is used as a proxy for service frequency).

**Table 1 Final Mode Choice Model for Spanish Town**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>( \beta )</th>
<th>Wald</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Journey Time (BRT 45 minutes)</td>
<td>.142</td>
<td>.034</td>
<td>.853</td>
</tr>
<tr>
<td>Journey Time (Rail 15 minutes)</td>
<td>-3.958</td>
<td>2.879</td>
<td>.003</td>
</tr>
<tr>
<td>Journey Time (Rail 25 minutes)</td>
<td>-20.934</td>
<td>5.345</td>
<td>.033</td>
</tr>
<tr>
<td>Travel Cost (BRT $200)</td>
<td>1.025</td>
<td>.948</td>
<td>.996</td>
</tr>
<tr>
<td>Travel Cost (Rail $200)</td>
<td>-5.24</td>
<td>.126</td>
<td>.023</td>
</tr>
<tr>
<td>Travel Cost (Rail $250)</td>
<td>-17.920</td>
<td>4.735</td>
<td>.016</td>
</tr>
<tr>
<td>Service Frequency (BRT every 30 minutes)</td>
<td>.841</td>
<td>.736</td>
<td>.391</td>
</tr>
<tr>
<td>Service Frequency (Rail every 30 minutes)</td>
<td>-3.331</td>
<td>2.745</td>
<td>.029</td>
</tr>
<tr>
<td>Service Frequency (Rail every 60 minutes)</td>
<td>-3.306</td>
<td>1.692</td>
<td>.017</td>
</tr>
</tbody>
</table>

**Base Levels:** JOURNEY TIME = BRT 35 minutes; TRAVEL COST = BRT $150; SERVICE FREQUENCY = BRT Every 15 minutes;

**SUMMARY STATISTICS**

- Number of observations = 833
- Hosmer and Lemshow =
- Cox and Snell = 0.685
- Nagelkerke = 0.945
- \( L (c) = 746.41 \)
- \( L (\beta) = 78.05 \)
Overall, JOURNEY TIME (25 minutes) is considered the most important parameter as shown by the coefficient estimate. Compared with the base level, when journey time is increased 10 minutes, respondents are more likely to choose rail. A reduction in journey time by 20 and 10 minutes however, increases the probability of using BRT. Additionally, clear differences emerge in the relative importance associated with increased journey times (-20.93 and -3.96 respectively) indicating respondents are far more likely to use BRT as journey time is reduced, but the effect on utility is significant in both cases.

The coefficient values for increased cost are also statistically significant except for a $50 increase in BRT costs, which increases the probability of using rail. When there are corresponding and further increases in rail costs, respondents are more likely to use BRT, as indicated by the sign of the coefficient estimates. There is also a noticeable difference in the relative values of the different costs, indicating higher costs impacts positively on the utility of BRT.

The value of the coefficient estimates for service frequency indicates respondents in Spanish Town attach less importance to waiting time. A 15 minutes increase in waiting time increases the probability of choosing rail but further increases result in a disutility for rail. An increase in waiting time of 15 minutes and 45 minutes significantly reduces the probability of using a rail service. The similar values for both 15 minutes and 45 minutes waiting time, both of which are associated with rail, implies a general agreement that respondents are more likely to use BRT when there are longer waiting times.

**Portmore**

The goodness-of-fit measures do not inspire confidence in the results from the Portmore analysis, yet the coefficient estimates are more in line with the literature on mode choice modelling. Table 2 displays the model results and measures range from 0.141 (Hosmer and Lemeshow), 0.092 (Cox and Snell) to 0.126 (Nagelkerke). The log likelihood value is 432.69, $\chi^2 = 232.20$. Similar to Spanish Town, the $H_0$ can be rejected that all $\beta$ are equal to zero, but although the estimates display the expected signs for the most part, only the SERVICE FREQUENCY parameters are statistically significant at the 95% confidence level.

**Table 2 Final Mode Choice Model for Portmore**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>$\beta$</th>
<th>Wald</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Journey Time (30 minutes)</td>
<td>1.458</td>
<td>0.201</td>
<td>0.654</td>
</tr>
<tr>
<td>Journey Time (10 minutes)</td>
<td>-0.106</td>
<td>1.897</td>
<td>0.168</td>
</tr>
<tr>
<td>Journey Time (15 minutes)</td>
<td>-0.024</td>
<td>0.019</td>
<td>0.890</td>
</tr>
<tr>
<td>Travel Cost ($180)</td>
<td>-0.089</td>
<td>0.129</td>
<td>0.272</td>
</tr>
<tr>
<td>Travel Cost ($150)</td>
<td>0.120</td>
<td>2.218</td>
<td>0.136</td>
</tr>
<tr>
<td>Travel Cost ($200)</td>
<td>-0.374</td>
<td>7.111</td>
<td>0.143</td>
</tr>
<tr>
<td>Service Frequency (BRT every 30 minutes)</td>
<td>-0.328</td>
<td>1.397</td>
<td><strong>0.024</strong></td>
</tr>
<tr>
<td>Service Frequency (Rail every 30 minutes)</td>
<td>-0.201</td>
<td>0.586</td>
<td><strong>0.046</strong></td>
</tr>
<tr>
<td>Service Frequency (Rail every 60 minutes)</td>
<td>-5.817</td>
<td>2.676</td>
<td><strong>0.001</strong></td>
</tr>
</tbody>
</table>
Base Levels: JOURNEY TIME = 20 minutes; TRAVEL COST = $130; SERVICE FREQUENCY = Every 15 minutes;

**SUMMARY STATISTICS**

<table>
<thead>
<tr>
<th>Number of observations</th>
<th>Hosmer and Lemshow</th>
<th>Cox and Snell</th>
<th>Nagelkerke</th>
<th>L (θ)</th>
<th>L (β)</th>
<th>Probability χ² (8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>778</td>
<td>0.141</td>
<td>0.092</td>
<td>0.126</td>
<td>664.89</td>
<td>432.69</td>
<td>232.20</td>
</tr>
</tbody>
</table>

**Base Outcome = BRT**

As can be seen from Table 2, there is a difference of opinion between respondents in both areas on the relative importance of the parameters. In Portmore, respondents attach more importance to SERVICE FREQUENCY in a choice between BRT and rail. The difference between SERVICE FREQUENCY (every 30 minutes) and SERVICE FREQUENCY (every 60 minutes) estimates suggest that the effect of increasing waiting time has considerably more impact on utility. The signs also suggest that any increase in waiting time is likely to influence respondents to choose BRT. All three parameters are statistically significant at the 95% confidence level.

TRAVEL COST does not significantly influence choice and the coefficient estimates indicate relatively little importance is attached to any of the three parameters. The signs suggest an increase of $50 or more creates a disutility for rail but the magnitude of the signs show increases in rail cost has a greater impact on utility than an increase in BRT cost. The coefficient estimates for JOURNEY TIME also has relatively little impact on utility. The magnitude and signs of all three parameter does suggest though, that an increase in journey time is likely to reduce the probability of using rail.

**Interpretation, Conclusion and Recommendations**

Improving urban public transport is one of the many strategies proposed to counter congestion and increasing car dependency. In the context of the KMTR, the effectiveness of improvements, whether by the introduction of a new public transport option or an improvement to the existing system, should be driven by the degree to which improvements justify an increase in fares, service frequency or a travel time reduction. There is a clear choice in Spanish Town for the preference of a BRT system determined by travel cost and journey time. The choice in Portmore is not as distinct but is driven by service frequency as indicated by the coefficient value. The difference in the relative importance of the variables between the two areas may be influenced by the distance to the KMA. Portmore is closer to the KMA and hence travel times are invariably shorter, suggesting waiting time (service frequency) is valued higher than the other attributes. It is therefore reasonable to assume then, that since the distance between Portmore and the KMA is relatively short, then journey time and travel cost between rail and BRT would not be significantly different. The public transport mode that offers shorter waiting time will likely be the preferred option then and probably attracts a higher patronage when compared with the other attributes.

In the same way however, care must be taken that the introduction of a new mode also addresses improvements in travel cost and/or journey time so that respondents in Spanish Town are not ambivalent or worse yet opposed to any proposed scheme, which could result in a net decrease in demand for the service. Direct or cross elasticities or a ratio of two coefficients is a common means of examining the effects of changes between the variables. Similar to Portmore then, the distance between Spanish Town and the KMA may be a significant influencing factor on choice of BRT, for respondents of Spanish Town. The result of the chi-square analysis shows significant relationships between income and travel behaviour, signifying that the relative importance attached to cost could be a function of the large number of low and medium income-
earners in this area. In the same way, the large coefficient value of journey time suggests a constant trade-off by respondents between the two attributes in an effort to maximise or at the very least, maintain the same level of utility.

At an aggregate level, a predisposition towards a bus-based system in Jamaica is not unusual despite the failings of the current system. It may be that the perception of rail travel in Jamaica reduces the likelihood of respondents choosing that option. This is because the now inoperable passenger rail system travelled at slow speeds, utilised old rolling stock, posed a safety risk when moving between carriages and had generally poor services (JNHT, 2009). The absence of a real experience with a rapid rail transit system may therefore preclude a respondent from selecting this alternative. This could also be a display of caution on the part of respondents who may seek to use BRT as a transitional public transport facility, which allows for gradual acceptance of a rail service in the future. Additionally, the perceived differences between a traditional bus system and bus rapid transit may not have been clearly defined and thus prompted the choice.

The effects of non-trading or lexicographical behaviour cannot be discounted then if the intent was to influence a policy decision or if choice was determined because of a single influencing factor. The non-trading behaviour reflects non-utility maximisation and refers in part to a respondent’s intent to influence the outcome of some policy initiative, in this case the introduction of a BRT or bus-based system. Lexicographic behaviour refers to a choice dependent on the attribute a respondent considers the preferred attribute, for example, a respondent who always chooses the fastest or cheapest alternative without considering whether other disadvantages exist. In this case the preferred alternative may not necessarily maximise utility. This brings into perspective the impressions from the results of the attitudinal data which indicated respondents were generally dissatisfied with public transport and in agreement that improvement to service quality and other perceptual attributes were necessary for increased patronage. The fact that the sample is approximately two thirds female in both towns is suggestive of the level of agreement to the attributes measured, since females are more sensitive to perceptual or ‘soft’ attributes. Service aspects such as reliability of service and journey time reliability were considered very important by respondents which may have influenced their choice. These attributes influence respondent’s perceptions and have implications for patronage levels and indeed mode switching decisions.

The findings presented here is a useful indication of respondent’s intent and preferences regarding new public transport modes. The introduction of a rapid transit system in the KMTR is not primarily to effect a modal shift but rather to facilitate the movement of public transport and promote an efficient multi-modal public transport system. This is necessary to address the issue of increasing congestion levels and promote efficient use of the road network. The success of such a system may then lead to secondary benefits of capturing potential private car users and stem rising car ownership levels. The recommended implementation of a BRT system in the KMTR requires considering all the attributes for effective uptake by respondents of both Spanish Town and Portmore. Government policy proposals will be best developed in packages that address issues of the more easily defined primary attributes – cost and time – in addition to less tangible ones such as comfort. The success of BRT systems elsewhere has shown that this is achievable and likely, more suitable to the Jamaican context because of comparable service quality characteristics, the high implementation costs and limited network coverage of rail transit. However, this requires a further look at the impacts of the attributes on mode choice, such as a valuation of travel time study to determine the marginal utility of travel cost and journey time. This would give an indication of the actual disutility of time spent travelling relative to the cost of time spent travelling and, a study on fare elasticities to determine a ratio of proportional change in fares relative to a proportional change in patronage, to determine at what levels greater market shares can be captured to ensure that the service, if implemented is sustained.
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The general objective of the ECOROADS project is to overcome the barrier established by the formal interpretation of the two Directives 2008/96/EC (on road infrastructure safety management) and 2004/54/EC (on tunnels), that in practice do not allow the same Road Safety Audits/Inspections to be performed inside tunnels. The main problem is that, while from the user (driver) point of view a road is a unique linear infrastructure generally in open terrain and sometimes in closed environment (tunnels), the strict application of the two Directives leads to a non-uniform approach to the infrastructure safety management outside and inside tunnels.

To overcome this barrier, ECOROADS projects aims at the establishment of a common enhanced approach to road infrastructure and tunnel safety management by using the concepts and criteria of the Directive 2008/96/CE on road infrastructure safety management and the results of related European Commission (EC) funded projects. Such an objective will be achieved through the following specific activities:

- Workshops with the stakeholders (European tunnel and road managers); Analysis/review of national practices regarding Road Safety Inspections (RSI) and Road Safety Audits (RSA), starting from the results of the two studies recently launched by the EC’s Directorate for Mobility and Transport to assess the impact of the two Directives 2008/96/EC and 2004/54/EC
- Exchange of best practices and experiences between European tunnel experts and road safety professionals
- Pilot joint safety operations in five European road sections which feature both open roads and tunnels
- Recommendations and guidelines for the application of the RSA and RSI concepts within the tunnel safety operations

Thanks to the high transferability of the ECOROADS results, the present formal gap between the Directive 2008/96/EC and the Directive 2004/54/EC will be bridged, thus leading to “faster, more sustainable and better planned interventions with maximum safety for the workers and other traffic participants”

The project is going to contribute to the implementation of coherent safety procedures on the whole road network, both at the Member State and EU level. Moreover, during the Stakeholder Conference on EU Directive 2008/96/EC held on 13th June 2014, the European Commission spoke about the possibility to merge the Directives together in 2016or 2017. This project will therefore provide valuable input to the work of the EC and the possible future revision of one or both Directives.

ECOROADS was submitted under the Horizon 2020 call 2014 - topic MG-8.1b-2014 “Smarter design, construction and maintenance” and was selected for financing. It started on 1st June 2015. This paper explains the basic concept and the criteria adopted for the test sites, together with the common approach agreed by the international stakeholders concerned.
Effective and coordinated road infrastructure safety operations

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¹Forum Des Laboratoires Nationaux Europeens De Recherche Routiere, Belgium;
²Italian Association of Road Safety Professionals, Italy
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1 INTRODUCTION

The general objective of the ECORoads project is to overcome the barrier established by the formal interpretation of the two Directives 2008/96/EC (on road infrastructure safety management) and 2004/54/EC (on tunnels), that in practice do not allow the same Road Safety Audits/Inspections to be performed inside tunnels, as shown in Figure 1.

Figure 1. The “conflict” between the two EU Directives

The main problem is that, while from the user (driver) point of view a road is a unique linear infrastructure generally in open terrain and sometimes in closed environment (tunnels), the strict application of the two Directives leads to a non-uniform approach to the infrastructure safety management outside and inside tunnels.
This project is the follow-up of the initiative related to the European Road Safety Directives and the two workshops held at the European Social and Economic Committee (EESC) by a group of international stakeholders in February and May 2013: a debate that was initiated as a result of the coach crash in Switzerland that caused more than 28 fatalities, including 22 children\(^1\)

The collision occurred in 2012 with the end wall of an emergency parking facility in the Sierre tunnel, Switzerland, which opened in 1999 and was rated as “good” in a 2005 European Tunnel Assessment Programme (EuroTAP) test. The end wall was placed at 90 degrees with respect to the direction of the adjacent traffic flow, without any adequate protection from collision.

![Figure 2. Yellow arrows indicate the 90 degree walls without any protection inside tunnels](image)

This feature of tunnel design is typical of many European tunnels, as shown in Figure 2 – 90 degrees walls without any protection -, where operations such as RSA during the design process or RSI after opening to traffic, according to the prescriptions of the Directive 2008/96/EC, could be beneficial for risk prevention.


On the other hand, Directive (2004/54/EC) does not deal directly with RSA or RSI inside the tunnels: There is only a general statement about taking "all aspects of the system composed of the infrastructure, operation, users and vehicles" into account in Annex 1. Different interpretation and application by Member States may further amplify the gap between the two Directives.

Some interested stakeholders organised a collection of signatures to address a petition\(^2\) to the EC at the beginning of the Decade of Action for Road Safety, in order to call for an initiative that aims to fill the

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\(^2\) [http://www.aipss.it/letter_to_the_commissioner.html](http://www.aipss.it/letter_to_the_commissioner.html)
gap between the two Directives and therefore contribute to the further reduction of road traffic collision fatalities in Europe.

The petition also recommended a series of workshops to find the way to integrate the two Directives, as well as a meeting of road safety delegates from Member States to agree common objectives to be achieved within this Decade. Following the reply from the Vice President Siim Kallas, in 2013 the EESC hosted two workshops dedicated to the issue³.

The participants, many of whom are represented in the ECOROADS project consortium, discussed the best way to deal with the two EC directives and suggested that studies might be needed, as well as reflections on what would be the most appropriate research and finally agreed to act under the umbrella of a Coordinating or Supporting Action to be submitted to Horizon 2020.

Thus, the ECOROADS informal consortium was set up, composed by the following thematic associations: FEHRL-Forum Des Laboratoires Nationaux Europeens De Recherche Routiere (Belgium); ETSC-European Transport Safety Council (Belgium); ERF-The European Union Road Federation (Belgium); ASECAP - European Association with tolled motorways, bridges and tunnels (Belgium); AIPSS-Italian Association of Road Safety Professionals (Italy); SEETO South East Europe Transport Observatory (Serbia)

The consortium started to draft a proposal aiming at the deployment of mixed groups of tunnel and road safety experts performing joint safety inspections in both tunnels and open roads, in order to find a common agreed inspection methodology able to enhance safety in roads and tunnels.

2 METHODOLOGY

The ECOROADS objective is to ensure that road users can circulate on European roads where uniform safety measures have been planned and implemented, avoiding different approaches stemming from formal discrepancies in the interpretation of EU Directives.

The overall approach of the ECOROADS is based on the previous successfully project Pilot4Safety and is divided into several phases, including a clear overview of the application of the two Directives in the Member States, a series of workshops with the stakeholders (European tunnel and road managers), and the exchange of best practices between European experts in the two fields:

Clear overview of the application of the two Directives in the Member States and the extent of the gap between them already described in the previous section. The analysis/review of national practices regarding Road Safety Inspections (RSI) and Road Safety Audit (RSA), starting from the results of the two studies recently launched by DG MOVE to assess the impact of the two Directives on road infrastructure safety management and tunnels. Such an overview will be the basis of a discussion with the stakeholders through dedicated workshops.

Workshops with the stakeholders (European tunnel and road managers from at least 10 European countries): three workshops will be organised according to the following schedule:

First workshop to discuss the results of the overview of the application of the two Directives and the details of the exchange of best practices and the joint safety operations described further on in this section.

Second workshop to be held after a first set of joint safety operations, in order to analyse the first results and fine tune the second set of joint operations.

³ (announcement, invitation and agenda are available at http://www.eesc.europa.eu/?i=portal.en.events-and-activities-road-safety)
Third final workshop to discuss the results of the operations and the first draft of the guidelines.

**Exchange of best practices and experiences between European tunnel experts and road safety professionals:** three working sessions in Brussels will be attended by safety experts belonging to the two groups (tunnel and roads) from European countries involved in the Action. The experts will spend two days for each session at FEHRL (Brussels), for a total of six days.

In the first session, the tunnel safety operations will be presented by the tunnel experts to the road experts, while in the second session the Road safety Audit and Inspection principles will be explained to the tunnel experts.

The third and last session will be used to plan the joint safety operations in five different locations in Europe, where each location will have a section on an open road together with a section in a tunnel. There will also be discussions/exchanges on technical aspects, such as the possible technological measures to mitigate the risk associated with lay-bys. Vehicle restraint systems are designed to work in a road environment not in a tunnel, which means that typical road solutions will not be directly implementable in tunnels.

A link to other EU projects, those outputs can feed into ECORoads are going to be established by the specific dissemination work package:

- RIPCORD-ISEREST
- SOLUTIONS: Sharing Opportunities for Low carbon Urban transportION
- ERA-NET ROAD 2009 "Safety at the Heart of Road Design"
- PILOT4SAFETY 2010-2012 Pilot project for common EU Curriculum for Road Safety experts: training and application on Secondary Roads
- ERA-NET ROAD 2010 “Effective Asset Management meeting Future Challenges”
- CEDR 2013 Theme C: Safety
- Moreover,
  - Guideline for safety evaluations of road tunnels according to RABT 2006 (Section 0.5)
  - Konzeption der Sicherheitsdokumentation für Straßentunnel nach EG - Richtlinie 2004/54/EG
  - Leitfaden zur Erstellung einer Sicherheitsdokumentation gemäß RABT 2006 (Abschnitt 1.1.5)

After several discussions among the project partners, a preliminary long list of field tests has been identified in Table 1. Five definitive locations will be decided during the first project workshop.
### Table 1 - Long list of test sites

<table>
<thead>
<tr>
<th>Number</th>
<th>Country</th>
<th>Test Site Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Germany - Bundesautobahn (BAB) A71</td>
<td>between AS Geraberg and AD Suhl BAB A71 between AS Geraberg and AD Suhl</td>
</tr>
<tr>
<td>2.</td>
<td>Germany - E55/BAB A17</td>
<td>between AS Dresden-Gorbitz and AS Dresden-Südvorstadt</td>
</tr>
<tr>
<td>3.</td>
<td>Belgium - Kennedytunnel, Antwerp</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Czech Republic - Tunnel Klimkovice</td>
<td>Road category: Four lane motorway D47 (TENT network)</td>
</tr>
<tr>
<td>5.</td>
<td>Albania - Tirane (Ring road)</td>
<td>– Elbasan - Corridor VIII - SEETO Area</td>
</tr>
<tr>
<td>6.</td>
<td>Tirane (Brari Bridge) - Vasha Bridge (Bulqizë)</td>
<td>- SEETO Area</td>
</tr>
<tr>
<td>7.</td>
<td>Bosnia and Herzegovina Karuse-Ozimica - Corridor Vc</td>
<td>- SEETO Area</td>
</tr>
<tr>
<td>8.</td>
<td>Bosnia and Herzegovina Topcic Polje-Lasva - Corridor Vc</td>
<td>- SEETO Area</td>
</tr>
<tr>
<td>9.</td>
<td>Bosnia and Herzegovina Ustipraca-Medjedja</td>
<td>SEETO Route 3 - SEETO Area</td>
</tr>
<tr>
<td>10.</td>
<td>Montenegro Bypass Rozaje</td>
<td>SEETO Route 6a - SEETO Area</td>
</tr>
<tr>
<td>11.</td>
<td>The former Yugoslav Republic of Macedonia Veles-Katlanovo</td>
<td>Corridor X - SEETO Area</td>
</tr>
<tr>
<td>12.</td>
<td>The former Yugoslav Republic of Macedonia Demir Kapija-Udovo Corridor X</td>
<td>- SEETO Area</td>
</tr>
<tr>
<td>13.</td>
<td>Serbia Belgrade by pass</td>
<td>- Sector 5 Corridor X - SEETO Area</td>
</tr>
<tr>
<td>14.</td>
<td>Serbia Dimitrovgrad bypass</td>
<td>- Corridor Xc - SEETO Area</td>
</tr>
<tr>
<td>15.</td>
<td>Italy Regional Road 3</td>
<td>“Via Flaminia”, 2 km north from the ring of Rome</td>
</tr>
</tbody>
</table>

It is to be underlined that more locations can be proposed, even by Road Authorities not directly participating at the project, just by submitting the candidature before the Workshop 1 and by guaranteeing the availability of the site and the safety measures for the inspectors (traffic calming, presence of the Police, etc.); the number of effective operation could therefore be higher than the five originally scheduled, depending of the cost of each operation respect to the assigned budget.

Common (road and tunnels) inspection procedures for the test fields will be agreed by the partners, taking into account the following aspects:

- **Composition of the joint team:** at least three experts, with minimum one road and one tunnel expert, coming from different countries; participation of further people as “observers” is allowed
- **Checklists:** The usage of checklists should not been mandatory during the inspection, but it is recommended to use them, especially after conducting the inspection
- **Safety of the inspection team and other road users during the operations**
- **Modern technologies:** definition of cameras and/or other specific tools that can possibly be used and a standard procedure
- **Point of view of all road users:** the inspection should not only be car oriented. It is necessary to check the safety issues from the point of view of all road users allowed to use the infrastructure.
- **Inspection report:** scheme and content of the report, including the relative importance of each deficiency, in order to allow the infrastructure manager to take appropriate decisions
- **Feedback from the infrastructure manager:** scheme of the written response the road authority should provide after having received and analysed the report

379
3 EXPECTED RESULTS

The main impact of the project is to overcome the barrier established by a formal interpretation of the two Directives which do not currently allow infrastructure safety checks (RSI and RSA) to be performed inside tunnels. ECOROADS will deliver a common approach to road infrastructure safety monitoring, thus optimising the time, quality and costs of the safety checks.

This project will harmonise infrastructure safety monitoring: the life span of ageing infrastructure, particularly in the transition areas between tunnels and the open road, will therefore be extended due to better attention being given to their inspection. The Guidelines and Recommendations delivered by the project are an effective tool to meet cost-effectiveness and sustainability goals.

4 CONCLUSIONS

ECOROADS was submitted under the Horizon 2020 call 2014 - topic MG-8.1b-2014 “Smarter design, construction and maintenance” and was selected for financing with a start date of June 2015. It will lead to a fruitful exchange of experiences, the cross-fertilisation between the two disciplines of tunnel safety and road safety and better implementation of all safety operations along road infrastructures.

The project will allow good practices to be shared and define a common agreed approach for applying the concepts of the Directive 2008/96/CE on road infrastructure safety management in tunnels and in the transition areas between tunnels and open roads, without affecting (but completing) the usual tunnel safety management operations.
Thanks to the high transferability of the ECORoads results, the present formal gap (explained in
detail in the following paragraph) between the Directive 2008/96/EC and the Directive 2004/54/EC will be
bridged, thus leading to faster, more sustainable and better planned interventions with maximum safety for
the workers and other traffic participants, according to needs of “Effective and COordinated ROAD
infrastructure Safety operations”. The project will thus contribute to the implementation of coherent safety
procedures on the whole road network, both at the Member State and EU level.

Moreover, during the Stakeholder Conference on EU Directive 2008/96/EC held on 13th June 2014,
the possibility to merge the Directives together in 2016 was not excluded, depending on the stakeholders’
position and the next Commissioner’s approach.

**This project will therefore provide valuable input to the work of the EC and the possible
future revision of one or both Directives.**

Moreover, up to early 2017 and depending to the budget availability, there will be the possibility to
add more test sites: any interested stakeholder from Europe and Neighbourhood Countries may ask to the
project to include a site visit on a specific location.

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EU Directive 2004/54/EC on minimum safety requirements for tunnels in the Trans-European Road
Network
Open letter to the EU Commissioner on Transport [http://www.aipss.it/letter_to_the_commissioner.html](http://www.aipss.it/letter_to_the_commissioner.html)
HORIZON 2020 - Work Programme 2014 – 2015: Smart, green and integrated transport
PILOT4SAFETY 2010-2012 Pilot project for common EU Curriculum for Road Safety experts: training
and application on Secondary Roads
ABSTRACT:

Every year thousands of people die in traffic accidents in the European Union. In 2013, around 4,300 people lost their lives in an accident involving trucks or heavy goods vehicles (HGV). 35% of these fatalities occur during non-daylight hours.

EU Directive 2007/35 requires since July 2011, all newly registered heavy trucks (N2 and N3) and their trailers (O3 and O4) to be fitted with retro-reflective contour markings, making them much more visible for drivers. Currently, contour marking is not compulsory for older vehicles of the same type. About 3 million trucks and trailers registered before 2011 continue to pose a potential risk and cause fatalities.

This paper will highlight the actions of three EU member states - Italy, Romania and Slovakia - having already introduced a legal obligation for existing vehicles and trailers to be fitted with retro-reflective contour marking. An analysis of European Commission data, shows the impact in Italy of a 36% reduction in night-time accidents, while other EU member states registered only an 18% reduction.

Secondly, a more recent study (January 2015) by the national institute for scientific road safety research (SWOV) in the Netherlands concluded that retro-fitting existing vehicles in the EU would prevent the loss of no less than 429 lives, 2,282 serious injuries and 68,000 accidents. Hence, if all 3.4 million vehicles, registered prior to July 2011, would apply ECE104 retro-reflective contour markings, the benefit-cost ratio (BCR) would be between 3 and 6, meaning that a retrofit investment between €267 and 500 million maximum would result in a socio-economic benefit of €1.5 billion. If no action is taken, unmarked, dark vehicles would remain on EU roads till 2033. Such a high BCR indicates a more substantial impact compared
to the analysis of 50 newly proposed vehicle safety measures (recent TRL report to the EU Commission).

These compelling numbers indicate the "low hanging fruit" regulatory opportunity in making roads and vehicles safer.

Also Turkey complies with the new UN ECE 48 and UN ECE 104 regulations. Various efforts have been done to motivate HGV owners and drivers to comply or apply UN ECE 104 material on a voluntary basis.
Safety Studies and Accident Analysis covering ECE104 Reflective Contourmarkings on Heavy Goods Vehicles

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1 INTRODUCTION – SUMMARY

Every year thousands of people die in traffic accidents in the European Union. In 2013, around 4,300 people lost their lives in an accident involving trucks or heavy goods vehicles (HGV). 35% of these fatalities occur during non-daylight hours.

EU Directive 2007/35 requires since July 2011, all newly registered heavy trucks (N2 and N3) and their trailers (O3 and O4) to be fitted with retro-reflective contour markings, making them much more visible for drivers. Currently, contour marking is not compulsory for older vehicles of the same type. About 3 million trucks and trailers registered before 2011 continue to pose a potential risk and cause fatalities.

This paper will highlight the actions of three EU member states - Italy, Romania and Slovakia - having already introduced a legal obligation for existing vehicles and trailers to be fitted with retro-reflective contour marking.

Secondly, a more recent study (published in January 2015) by the National Institute for Scientific Road Safety Research (SWOV) in the Netherlands concluded that retro-fitting existing vehicles in the EU would prevent the loss of no less than 429 lives, 2,282 serious injuries and 68,000 accidents. The benefit-cost ratio (BCR) would be between 3 and probably even closer to 6. If no action is taken, unmarked, dark vehicles would remain on EU roads till 2033. Such a high BCR indicates a more substantial impact compared to the analysis of 50 newly proposed vehicle safety measures (recent TRL report to the EU Commission).

Also Turkey decided to transpose the EU Directive 2007/35 into national law. The paper covers the joint efforts by several ministries, as well as media coverage motivating the HGV owners and drivers to comply with this regulation and only go for the type approved materials defined by UN ECE 104.

2 CURRENT REGULATORY FRAMEWORK

In 2007, UN ECE WP29 adopted Regulation 48 Clause 6.21 to include mandatory reflective contour markings for commercial vehicles : N2 > 7.5t, N3, O3 and O4. The European Union transposed this regulation by Directive 2007/35/EC. The first impact was in 2009 for new type approvals. The largest impact was noticed in July 2011, when the new regulation covered all new registrations more than 7.5 tonnes, more than 6.00 metres long and more than 2.10 metres.

M1 (normal passenger cars) and O1 (small trailers) are not allowed to be equipped with ECE104 material. For the remaining vehicle types the contour markings are allowed.

Figure 1: Example of a lorry compliant to UN ECE 48 Clause 6.21
The contour marking consists of 50 mm wide reflective strips, which must be approved in accordance with ECE-R 104. These strips must be affixed as a technical lighting facility in accordance with ECE-R 48, and will therefore be subject to the general and roadside inspections.

In accordance with these, the conspicuous contour marking must always consist of rear and side marking whereby the rear marking must be attached as a full contour marking in either yellow or red and the side marking at least as partial contour marking in yellow or white – full contour marking at the side as an option.

Table 2 provides an overview of the types of vehicles covered by regulation 48, clause 6.21 (ECE 104 reflective contour markings):

<table>
<thead>
<tr>
<th>Vehicle Category</th>
<th>Sub - Category and Max. Mass in tonnes</th>
<th>Max # passengers (excl. driver)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M (Passenger transport)</td>
<td>M1 (Passenger Car)</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>M2 (Bus) Mass ≤ 5 T</td>
<td>&gt;8</td>
</tr>
<tr>
<td></td>
<td>M3 (Bus) Mass &gt; 5 T</td>
<td>&gt;8</td>
</tr>
<tr>
<td>N (Commercial Vehicles)</td>
<td>N1 Mass ≤ 3.5 T</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>N2 3.5 &lt; Mass ≤ 7.5 T</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>N2 7.5 &lt; Mass ≤ 12 T</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>N3 Mass &gt; 12 T</td>
<td>N.A.</td>
</tr>
<tr>
<td>O (Trailers &amp; Semi Trailers)</td>
<td>O1 Mass ≤ 0.75 T</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>O2 0.75 &lt; Mass ≤ 3.5 T</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>O3 3.5 &lt; Mass ≤ 10 T</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>O4 Mass &gt; 10 T</td>
<td>N.A.</td>
</tr>
</tbody>
</table>

Table 2: Vehicles categories and contour markings ECE104

3. ITALY, ROMANIA AND SLOVAKIA: AHEAD OF THE EU REGULATION

Several countries did not wait for Directive 2007/35/EC, and implemented changes in their national traffic code by issuing ministerial decrees, asking for mandatory ECE104 markings on new and existing commercial vehicles and trailers.

Italy issued in Gazzetta Ufficiale N. 44 del 23 Febbraio 2005, MINISTERO DELLE INFRASTRUTTURE E DEI TRASPORTI DECRETO 27 Dicembre 2004, asking for ECE104 markings on all vehicles and trailers > 3.5t. (Published in the Official Gazette No 44 on February 23rd 2005). The full implementation came in 2006.
The impact of this regulation has been assessed based on several Road Safety Fact Sheets on HGV (Heavy Goods Vehicles) and Buses, published in ERSO (European Road Safety Observatory) covering accident statistics and analysis for 2004, 2005, 2008, 2009 (Note that the analysis for 2006 and 2007 is not available on the ERSO website) (1).

For these 4 years, fatalities in accidents involving HGV in Italy can be compared to 10 other EU memberstates: Austria, Belgium, Denmark, Finland, France, Greece, Portugal, Spain, Sweden and UK. For the other EU countries, these 4 years were missing or incomplete. 2004 and 2005 cover the situation just before the Italian regulation, while 2008 and 2009 are representative to measure the post impact of the ministrial decree. No other safety measures have been recorded during this evaluation period.

From 2005 to 2008, Italy dropped 36% in night time fatalities while the other 10 memberstates only noticed 18% reduction. The positive effect further continued in 2009.

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>2004</th>
<th>2005</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>Day</td>
<td>221</td>
<td>198</td>
<td>202</td>
<td>133</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>135</td>
<td>122</td>
<td>76</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>356</td>
<td>320</td>
<td>280</td>
<td>195</td>
</tr>
<tr>
<td>EU 10</td>
<td>Day</td>
<td>2103</td>
<td>1979</td>
<td>1313</td>
<td>1246</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>958</td>
<td>811</td>
<td>635</td>
<td>647</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3061</td>
<td>2790</td>
<td>2151</td>
<td>1891</td>
</tr>
</tbody>
</table>

Table 3: Fatalities in accidents involving HGV: Italy versus 10 other EU memberstates.

Also Romania implemented a similar regulation in 2006 with immediate effect. More accurate road safety statistics are not available but the Road Safety Fact Sheets on HGV and Buses, published in ERSO by the European Commission in 2010, 2011 and 2012 (covering 2008, 2009 and 2010 respectively), indicate a continuous and more noticeable reduction in night time fatalities. At night 48% less fatalities, while for daytime hours a reduction of 35% has been calculated. (1)

Table 4: Fatalities in accidents involving HGV
Slovakia decided in 2009 for a stepwise introduction of ECE104 marking for the existing and new HGV fleet: Government Act No. 349/2009 in force on October 10th 2009 and valid for all vehicles above 7.5 t (classes N) + trailers O3, O4, registered in Slovakia defines:

- 1\textsuperscript{st} phase started October 10th 2009 for all vehicles registered after 10.10.2009
- 2\textsuperscript{nd} phase started July 1st 2010 for all vehicles registered from 1.1.2005 to 10.10.2009
- 3\textsuperscript{rd} phase started January 1\textsuperscript{st} 2011 for all vehicles registered from 1.1.2000 to 31.12.2004

No accident statistics were found to measure the road safety benefit of this regulation.

4 FURTHER STUDIES BY SWOV

Early 2015, SWOV, the Dutch Road Safety Research Institute, conducted a Benefit Cost study about the possible impact of the a retrofit regulation, putting the rest of the EU in line with Italy, Romania and Slovakia.

A. The first part of the study focused on a retrofit scenario for The Netherlands.

Benefit:

The Netherlands has an annual number of approximately 300 fatal or serious injury crashes involving trucks and trailers Part of these crashes are due to lateral and rear-end collisions at dusk or in the dark. Previous SWOV research has shown that contour marking on trucks can contribute to the prevention of these types of crashes.

Number of vehicles without contour markings:

From CBS data, one can conclude that the life of a truck and tractor with semitrailer is about 13 years. Normal trailers remain about 22 years. A systematic introduction of ECE104 markings via new registrations would mean that the complete fleet would remain without marking for 11 years on average. Translating the effects found in Dutch and international research to the present situation in the Netherlands, indicates that retrofit contour marking leads to an estimated maximum prevention of 3 fatalities, 16 serious road injuries and 481 crashes per year. This data is only valid for a situation in which none of the vehicles in the Dutch vehicle fleet are fitted with contour marking and contour markings is applied to all vehicles at the same time. This is not the actual situation and trucks are replaced when their service life has ended. In addition, due to previous European legislation, contour marking will already be applied to part of the vehicle fleet on 1 January 2015 (the most optimistic estimate of a possible commencement date for the measure).

If the above is taken into account, the total savings over the period during which the measure is being introduced, which is from 1 January 2015 until contour marking has been applied to all trucks:

- 8 fatalities;
- 42 serious road injuries;
- 1268 crashes.

Cost estimates:

The costs of the retrofit introduction of contour marking for trucks in the Netherlands consist of the costs of the marking itself and the costs of applying the marking. The costs of applying the marking have been calculated for two different scenarios: a ‘maximum’ scenario in which full side contour markings are applied to the sides of all trucks, and a ‘minimum’ scenario in which only the bottom and the upper corners are marked, in accordance with the minimum requirements of the European Union.

Based on the minimum requirements in EU Directive 2007/35/EC or UN Directive ECE 48, Clause 6; 21, and market estimates, indicate that minimum marking will probably be chosen for many of the trucks. As it is difficult to indicate the exact number of involved trucks in advance and an earlier SWOV-report on contour marking also made the calculations based on the maximum marking, this maximum and minimum scenario were chosen for practical reasons and comparison options.

Following table 4.1 covers the average vehicle dimensions and amount of reflective material needed:

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Cargo bay</th>
<th>Cabin</th>
<th>Contour Marking Required (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length</td>
<td>Width</td>
<td>Height</td>
</tr>
<tr>
<td>Truck</td>
<td>7</td>
<td>2.5</td>
<td>2.4</td>
</tr>
<tr>
<td>Semi trailer</td>
<td>13</td>
<td>2.5</td>
<td>2.6</td>
</tr>
<tr>
<td>Tractor</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Trailer</td>
<td>8</td>
<td>2.5</td>
<td>2.6</td>
</tr>
</tbody>
</table>

*Table 4.1: Dimensions and material needed.*
The minimum scenario is also based on lower costs for the material (2.80 versus 2.00 euros per metre) and for applying the contour marking (130 versus 100 euro). The costs for legislation and information have not been included in the calculation of the costs. We estimate these costs to be minor. In our opinion the enforcement costs will not significantly increase. These costs have not been investigated because they are outside the scope of this study. The total estimated costs for the maximum scenario are 31 million euros and 16 million euros for the minimum scenario. As indicated above, the benefits of the measure on the social level are the casualties and crashes that are saved. For society, the benefits of retrofit introduction of contour marking amount to 35 million euros. For companies, the benefits consist of lower (insured and uninsured) costs as a result of the decrease in crashes. The benefits are estimated at 9 million euros for companies.

<table>
<thead>
<tr>
<th>Costs</th>
<th>Society</th>
<th>Transport Companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Costs</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>Minimum Costs</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Benefits</td>
<td>35</td>
<td>9</td>
</tr>
<tr>
<td>Balance benefits-costs</td>
<td>3</td>
<td>-22</td>
</tr>
<tr>
<td>BCR</td>
<td>1.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 4.2: BCR for the whole society and fleet owners

Costs and benefits of retrofit introduction of contour marking (in million euro cash values), and balance and ratio of costs and benefits. * Maximum scenario: full contour marking, price 2.80 euros per metre and application costs 130 euros. ** Minimum scenario: minimum required contour marking, price 2.00 euros per meter and application costs 100 euros.

The social benefits are slightly higher than the costs in the scenario with maximum costs, and twice as high as the costs in the scenario met minimum costs. This means that the social benefits are (slightly) positive. The ‘actual’ cost-benefit ratio will be determined by the amount of marking that is applied on the side of the truck and of the price development of contour marking. However, on the basis of the cost-benefit analysis, and in compliance with the restrictions indicated above, we may conclude that a retrofit introduction of contour marking is probably a sensible investment from an economic perspective and product prices continue to move lower. For individual transport companies the costs are about two to three times higher than the benefits. This means that solely in financial terms there is no strong incentive for companies to invest in contour marking on their own initiative.

B. Impact of a Retrofit program covering rest of Europe:

To translate the findings to the entire European Union, the necessary data was simply multiplied by the total number of inhabitants or the total vehicle fleet. The mortality in the EU as opposed to Dutch mortality was considered, not allowing for differences between countries concerning the age of truck, the real costs of tape and lettering and the real costs of damages and human losses. More precise data per EU country requires disproportionately more calculation, and in some cases more precise data is not available. The table below shows which aspects have and which aspects have not been included in the calculation. This report uses the rough estimation. The last column indicates which aspects could be further investigated in a fine estimate. This could be done in a follow-up study.
Table 4.3: Assumptions and consequences for the calculation of the effect in the EU

<table>
<thead>
<tr>
<th>Required Data</th>
<th>Rough Estimate</th>
<th>Takes account of</th>
<th>Does not take account of</th>
<th>Fine Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of casualties in this crash type in the EU</td>
<td>Number of casualties in NL, allowing for mortality ratios</td>
<td>Different number of inhabitants in the EU countries</td>
<td>Different number of fatalities/seriously injured per 100,000 inhabitants in the memberstates</td>
<td>Investigate in more detail using CARE data for max 19 member states.</td>
</tr>
<tr>
<td>Traffic mortality in EU member states</td>
<td>Average EU mortality versus NL mortality</td>
<td>Difference between EU mortality versus NL mortality</td>
<td>Differences in mortality between individual countries</td>
<td>Take into account the mortality in individual countries</td>
</tr>
<tr>
<td>The number of trucks in the EU and the period which they have been driving without contour marking</td>
<td>Translation of the number of NL truck years into truck years for the entire EU vehicle fleet</td>
<td>Differences in number of trucks between individual member states</td>
<td>Difference in age and life expectancy of trucks in individual EU countries.</td>
<td>Take into account the age and life expectancy of trucks in individual EU countries.</td>
</tr>
<tr>
<td>The costs of contour marking in the EU</td>
<td>Translation of the costs per NL truck to the total number of EU trucks, lowering the cost by a factor 2/3.</td>
<td>Estimate of the costs of ECE104 tape and application cost at 2/3 of the NL costs.</td>
<td>Real costs of applying contour marking</td>
<td>Retrieve info about the costs in a number of EU countries</td>
</tr>
<tr>
<td>The cost of casualty in the EU</td>
<td>Translation of the costs per NL casualty to the number of EU casualties, lowering the NL costs by a factor of 2/3.</td>
<td>Number of inhabitants in individual countries</td>
<td>Real crash costs/human losses in the individual countries</td>
<td>Retrieve information about the costs per casualty of a number of EU countries</td>
</tr>
<tr>
<td>Damage in Euro per crash</td>
<td>Extrapolate the cost of NL damages to the total of EU damages, lowering the cost by a factor 2/3.</td>
<td>Number of inhabitants and trucks per memberstate</td>
<td>Real cost of individual damages per individual country</td>
<td>Investigate whether individual countries use specific numbers.</td>
</tr>
</tbody>
</table>

As the calculation methods for the Netherlands and the EU are not the same, the road safety effect, the costs and the benefits are given for the EU, not including the Netherlands. Translated to the European Union not including the Netherlands, retrofit introduction of contour marking per 1 January 2015 is expected to result in a total saving of

- **421 fatalities**
- **2240 serious road injuries**
- **67,373 crashes**

over the period the measure is being put into effect. The costs of the measure amount to a total of 267 M€ in the minimum cost scenario and 517 M€ in the maximum cost scenario for the EU (minus the Netherlands). Converted to money, the total benefits of the measure for the EU minus the Netherlands amount to 1541 M€. Therefore the ratio between benefits and costs is 3 in the minimum cost scenario and 6 in the maximum cost scenario.

C. BCR for all of Europe, The Netherlands included

The total costs, benefits and benefit-cost ratio are calculated by adding the costs for the Netherlands and the European Union. It should be noted that the costs and benefits for the Netherlands have been calculated more accurately than the costs and benefits for the European Union: these latest figures are only a rough estimate. In the maximum cost scenario, the costs in the EU and in the Netherlands add up to 548 million euros, minimum cost scenario the total is 283 million euros. In both cases the benefits add up to 1576 million euros. The benefit-cost ratio therefore remains 3 for the maximum cost scenario and 6 for the minimum cost scenario.
This calculation of the costs does also not take into account costs for legislation and information and costs for enforcement are assumed not to increase significantly. These costs are not examined in this study, because they are outside the scope of the present investigation.

<table>
<thead>
<tr>
<th></th>
<th>Society</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum Costs (M€)*</td>
<td>Minimum Costs (M€)**</td>
<td></td>
</tr>
<tr>
<td>Costs</td>
<td>548</td>
<td>383</td>
<td></td>
</tr>
<tr>
<td>Benefits</td>
<td>1576</td>
<td>1576</td>
<td></td>
</tr>
<tr>
<td>Balance benefits - costs</td>
<td>1028</td>
<td>1293</td>
<td></td>
</tr>
<tr>
<td>BCR (Benefit/Costs Ratio)</td>
<td>3</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.4: Costs and benefits of retrofit introduction of contour marking (present values), and balance and ratio of costs and benefits in the EU including the Netherlands. Maximum scenario: full contour marking, two thirds of the Dutch price (marking 2.80 € per metre and application costs 130 € per truck) and two thirds of the Dutch benefits. **Minimum scenario: minimum required contour marking, two thirds of the Dutch price (marking 2.00 € per metre and application costs 100 € per truck).

5 RELATED ACTIVITIES IN TURKEY

In Turkey; since October 2012 conspicuity countermarking has been mandatory for N2 (7.5-12t), N3, O3, and O4 vehicle classes for the vehicles that has been manufactured after 2011. Conspicuity on these vehicles has been inspected in TÜV stations countrywide. Inspectors only check whether the vehicles have the conspicuity product or not, however they do not measure the reflectivity of the products.

There is not yet a history regarding the fatal/non fatal accidents subject to these classes before and after the regulation. But, there has been a solid implementation of the mandate on these vehicles.

In order to expand and cover the relevant classes, references in Italy, Slovenia and Romania may be taken into consideration to cover entire N2 class.

6 CONCLUSIONS

Both the analysis of night time accidents involving HGV in Italy, as well as the extensive study made by SWOV in 2014, clearly show the immediate road safety impact a retrofit program of retroreflective contourmarkings (ECE104) can have.

Night time accidents went down twice as fast in Italy versus other European member states since the introduction of the respective regulation in 2005.

The SWOV study confirms the original studies that lead to the EU Directive 2007/35/EC and transposed the revised UNECE Regulation 48, with a similar BCR of minimum 3 to probably closer to 6. As the study did not consider most trucks and trailers to have a second life in the second hand marked and to remain on EU roads for many more years.

Compared to the EU Directive 2007/37/EC that introduced a mandatoray retrofit for blind spot mirrors on HGV, a retrofit for conspicuity refit is much less complex, as ECE104 retroreflective markings are less costly and much more easy to apply.

Many of the proposed design and ITS improvements to new to be build vehicles will only have an impact as of 2020 due to the low number in the first years of implementation.

Therefor a conspicuity marking retrofit program is “low hanging fruit” in the EU wide actions to improve road safety.

7 ACKNOWLEDGEMENTS

Mr Wijnen, Dr Henk Stipdonk and Dr Charlotte Bax, SWOV, The Hague, Netherlands
Ing. Antonio Erario, Ministry of Infrastructure and Transport, Roma, Italia

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Regulation No. 48 (2008) “Uniform provisions concerning the approval of vehicles with regard to the installation of lighting and light-signalling devices“ Rev.1/Add.47/Rev.5 United Nations


IMPLEMENTING AUTOMATED TRAFFIC ENFORCEMENT IN EMERGING ECONOMIES

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ABSTRACT

In all emerging economies motorised mobility has increased with economic growth. Simultaneously road safety has suffered dramatically. Expansion of the police force in line with the enormous increase in vehicles in order to maintain adequate enforcement levels is no longer feasible. This encourages these countries to incorporate automated traffic enforcement into their road safety strategy. Moreover, traffic police forces, as an essential, qualified, costly and limited resource should focus on tasks which cannot be automated.

This policy paper does not present research results with conclusions. Rather, it presents recommendations to policy makers based on the various multi-disciplinary aspects of the “enforcement chain”. In particular with automated enforcement (e.g. speed and red light cameras) this chain concept is crucial: if one link is not effective or efficient, enforcement and road safety are compromised. The enforcement chain consists of a dozen links from detection and measurement to fine collection and court proceedings. Many counties struggle to get the wide range of multi-disciplinary aspects of the enforcement chain right and are thus not able to optimise their automated enforcement to further improve road safety. Key bottlenecks in the automated enforcement chain can be found e.g. when:

1) political and administrative support for automated traffic enforcement are wavering,
2) the legal and operational framework and its processing capacity are not geared to dealing with automated traffic enforcement and the resulting increase in the amount of traffic violations,
3) the license plate/vehicle owner and/or driving license administration are not in order,
4) inadequate requirements for the legal integrity of evidence and equipment homologation,
5) ticket processing, issuance and fine collection are ineffective and inefficient,
6) authorities argue over ticket revenue and funding of road safety investments e.g. enforcement and processing equipment, software and maintenance,
7) public support suffers because the background, results and road safety benefits of enforcement are not sufficiently published in various media and fines could merely be seen as a tax or revenue generator for the government.

Recognising the various actions required to create the proper preconditions and optimise the enforcement chain can prevent inefficacies and inefficiencies and make automated traffic enforcement what it can be: an effective tool to improve and maintain road safety in emerging economies.

1. INTRODUCTION

When motorised mobility starts to increase with economic growth road safety suffers dramatically. Crash and casualty statistics in many emerging economies illustrate this. The increase in motorisation far outpaces the expansion and quality of the available infrastructure. Moreover, investment for the lagging infrastructure expansion mostly focuses on extension and widening of the road network, not on incorporating road safety features or proper maintenance programmes. Quantity triumphs quality.

A capacity related issue can also be seen in the area of enforcement. Expanding manual traffic enforcement by increasing the number of police officers to cope with the higher traffic volumes and expanded infrastructure is no longer feasible and often not desirable. Especially for speed and red light violations automated enforcement cameras have shown to be very effective from a road safety, operational and cost perspective. This has repeatedly been confirmed by academic research in various studies. In many developing countries adding automatic speed cameras, to compliment manual enforcement by sometimes subjective local police officers centralises fine revenue collection, reduces ‘fine leakage’ and thus results in a more efficient, fairer and higher fine collection. The traffic police, as an essential, qualified, costly and limited resource should be used for tasks which cannot be automated i.e. checking for alcohol, helmet, seat
belt and mobile phone (ab)use. These opportunities encourage many emerging economies to incorporate automated traffic enforcement into their road safety strategy.

Traffic enforcement with cameras can only be effective if certain preconditions are met, and if the automated enforcement chain is effective and efficient. The enforcement chain is a sequence of events and actions from the initial detection of a violation to the final verdict in a court of justice on that violation. In case of an observation by a police officer the enforcement chain is relatively simple. In a court of justice, based on the police oath, the judgement of a police officer on a traffic violation prevails over that of the violator. However, when that judgement is transferred from an officer to a technical device such as a camera various issues arise. When not properly resolved these could have a detrimental effect on the enforcement chain and thus on road safety.

This policy paper deals with automated traffic enforcement and certain required preconditions. It also raises various issues with respect to links in the enforcement chain meant to make enforcement a proper road safety tool. Several countries struggle to make a smooth start with automated enforcement since it involves a range of multi-disciplinary changes which involve various ministries and other (semi-) government organisations, often at different administrative levels. The consequences of not getting the automated enforcement chain and its preconditions right leads, at best, to a sub-optimal investment of public finances and a failure to maximise the road safety benefit of enforcement. At worst, it could lead to a longer term suspension of automated enforcement with a painful legal, administrative or operational repair process, financial losses and a postponed reduction in traffic casualties, injuries and crashes.

This article subsequently deals with the preconditions for automated enforcement, then a step by step description of the enforcement chain links indicating specific bottlenecks. Recommendations are given to resolve these bottlenecks in order to improve the efficiency and efficacy of automated enforcement.

2. PRECONDITIONS

Certain preconditions need to met for automated enforcement to be effective. Some of these conditions e.g. a proper legal framework and an up-to-date vehicle registration, are virtually a must. Others may have a slightly lower priority but nevertheless play a key role in the enforcement chain and thus contribute to a successful road safety policy.

2.1 Legal preconditions

When prosecuting offending drivers with automated enforcement equipment governments need to specifically incorporate such enforcement and its operational conditions into its laws and related procedures since automated enforcement is inherently different from manual enforcement by police officers. An important legal starting point for automated enforcement is the choice between owner and driver liability.

With owner liability the ultimate responsibility for violations registered with automated enforcement systems lies with the owner of the vehicle. It does not matter if he or she was not driving; the vehicle owner is liable for all the traffic fines. If the owner did not commit the traffic violation, it is up to him or her to recover the fine from the person driving the vehicle. This also means that an image with license plate on a vehicle together with violation data such as time, location, nature of the violation, etc. is sufficient for prosecution.

With driver liability the driver of the violating vehicle is responsible. This means a image or video of a vehicle with a recognisable face of the driver and a license plate is required in order for a violation to be legally valid. Counties with driver liability (e.g. Germany, Switzerland, Denmark, Sweden, Poland and Japan) therefore take violation photos from the front of the vehicle. Even with driver liability the license plate is used to identify the owner who is then asked to identify the driver if the owner was not driving at the time of the violation.

The choice for owner or driver liability has great implications in various other areas. Prosecuting motorcyclists with a helmet is a problem with driver liability. Managing a demerit point driver license system is more challenging with owner liability. The European Transport Safety Council (ETSC) states that legal regimes with owner liability are better in reaping road safety benefits with their automated enforcement systems. Processing the huge number of violations resulting from automated enforcement programmes can be done very efficiently and with little or without human intervention by means of ANPR (Automatic Number Plate Recognition) under an owner liability regime. Driver liability is labour intensive and operationally costly due to the matching requirement of the vehicle owner with the actual driver at the time of violation. Moreover, due to e.g. lighting conditions, glare, coatings on car windows or intentional obstruction, recognisability of the driver on an evidence photo may be difficult, which reduces the prosecutability rate of the registered violations. According to data reported from the state Baden
Württemberg in driver-liability Germany, two-thirds of the image-based violations are stalled (including foreign vehicles and motorcyclists).

Other issues with need attention from a legal perspective include applying administrative law instead of criminal law for relatively common and light traffic offences. There is a considerable risk that the huge number of registered traffic violations (e.g. annually around 10 million in the Netherlands) generated by a large automated enforcement camera programme could cripple the court system if they cannot be settled effectively and efficiently by means of administrative fines. With administrative law a violation is legally not pursued further provided a fine or rather administrative sanction is paid. Not paying sanctions in time will not result in a lengthy prosecution through the legal system. However, it leads to rapid increases of the fine as specified in the fine notification. If fine payment is still not forthcoming it can, for example, be collected by impounding property or high-jacking the violator’s bank account. In the Netherlands a court appeal to an administrative sanction can only be accepted if the fine is paid first. If challenged successfully, it will be refunded. This rule drastically reduced the number of violations processed through the court system. Severe traffic violations (e.g. drunk driving, excessive speeding and violations resulting in crashes) in countries with administrative law regimes remain subject to criminal law.

Based on the above the recommendation for emerging economies planning to use automated enforcement would be to have a legal framework based on owner liability with administrative law to efficiently process light and frequent traffic violations. Additionally, the creation of a forceful and effective fine collection system based on a solid vehicle registration database will prevent an overloaded judiciary.

2.2 Legal integrity of the evidence

Over the past years legal challenges caused several camera enforcement programmes in various parts of the world to be terminated due to irregularities with data integrity, the measurement process or its accuracy. Evidence integrity is an essential precondition for the proper functioning of the enforcement chain and refers to two key aspects:

- Accurate, valid and all-inclusive measurements
- Evidence data integrity

Accurate and valid measurements

For the violator at the start of the enforcement chain and eventually also for the judge at the end of the chain there should be absolute certainty that e.g. the BAC (blood alcohol content) or speed of a violation is measured accurately. When violations are challenged judges and public prosecutors need to be able to refer to independent objective references which confirm the accuracy of measurements. Such reference is provided by an official certificate after a type approval procedure, issued by a government or authorised institute involved in testing equipment for measurement accuracy (e.g. PTB (Germany), LNE (France), NMi Certin (Netherlands) or METAS (Switzerland)). Regular (often annual) verification is also legally required to confirm that measurements remain accurate and valid. This verification, and if required calibration, is especially important for speed enforcement and BAC testing equipment. The use of enforcement equipment without certification and regular calibration is often not allowed and such measurements are not considered legally valid. For the judiciary but also for the violator these procedures guarantee that measurements are impartial, reliable and accurate and prove indisputably that indeed an violation occurred. A low success rate for legal challenges is important since it discourages future disputes and, consequently, lowers the future workload of the judiciary.

Besides accuracy, measurement institutes dealing with type approval increasingly require e.g. a 97% vehicle detection rate and that 95% of passing vehicles are actually speed measured. Type approval test take place in laboratories, field tests and after actual installation. Such test data are collected under night/day, various seasonal and weather conditions in practical tests spread over several days. Some governments also have strict requirements on the read rate and error rate for ANPR systems.

Besides measurement accuracy and detection, read and error rates, the measurement validity needs to be tested. Invalid readings (a false positive, e.g. a car overtaken by a speeding vehicle is registered as violator) should be eliminated by either not registering such evidence or marking the registered evidence as invalid. Cheaper inferior equipment may lead to missing certain violations (false negatives, e.g. not detecting a speeding motorbike). Inaccurate and invalid measurements may cause unjust violation notices, driving license suspensions and revocations (especially damaging for professional drivers) and unwarranted fines. Missing violations could lead to a feeling of injustice (why me and not him). These cases could undermine the credibility of enforcement, which in turn may hamper road safety.
Evidence data integrity
The evidence of a violation should be registered permanently and securely. In the past, with analogue wet film as evidence this was not an issue since there was only one original hardcopy negative which included all violation data. Tampering with the photo negative clearly leaves marks. However, this changed with the introduction of digital enforcement cameras and the registration of digital images, videos and violation data. Thorough tests are required to confirm that the digital evidence is secured with data encryption, authentication and/or integrity standards during data registration, transfer, storage and retrieval. Once registered there needs to be absolute certainty that violation data are confidential, secure, permanent, read-only and rendered invalid when changed. Type approval institutes check for various aspects of data integrity as a key condition for equipment certification. For governments using automated enforcement this paragraph confirms the legal importance of evidence data integrity, type approval, verification and calibration procedures by independent organisations.

2.3. Operational preconditions
Since automated enforcement is based on recognising vehicles by means of license plates, an accurate up-to-date vehicle and owner registration database is a prerequisite for such enforcement. This also applies to driver liability countries, since the initial contact point is always the vehicle owner. Another requirement is a driving license database to verify the validity of driving authorisations and, when applicable, the related demerit points of the driver in question. This is particularly relevant in driver liability countries. Demerit points are subtracted in connection with the severity of a violation and may result in driving license suspensions. Arranging proper access authorisations to such databases by authorities involved in the enforcement chain is crucial.

A complicating issue, also in light of legal equality, is how to deal with violations involving foreign vehicles. It is considered unjust if vehicles with foreign license plates can speed and escape fines because the vehicle owner cannot be traced. It is estimated that in France an average of 25% of the speeding violations is committed by foreign vehicles. This figure goes up to 40-50% during peak travel periods. This is issue was resolved recently with the EU Cross Border Enforcement (CBE) Directive. This allows access to the various national vehicle registration databases by most EU countries. Under the CBE violations for eight types of road safety related traffic violations can be sent to the owner in the language of the country of the violating vehicle. For many emerging economies this may not a viable option. In this case the license plate of the violating vehicle will have to be checked against a database with open unpaid citations at the border. In these cases fine payment has to take place on the spot as a condition to leave or enter a country.

In many countries license plate databases are much more than a link between the license plate, owner and address. They also include other data on vehicle type, length, width, weight, axles, engine size and type, exhaust systems and emissions, etc. These data give authorities traffic management opportunities. The City of Amsterdam effectively keeps older trucks and buses with polluting diesel engines out of the city centre with an environmental zone system based on engine and particle filter information stored in the national vehicle registration database. Violating vehicles are fined 230 euros. Dedicated bus lanes, stations squares, central city areas and shopping streets can also be kept car or truck free in a similar way.

2.4. Political support and Funding
Economic growth often follows a pattern whereby initially the development priority is on expansion of infrastructure. Political attention to road safety often comes later when the increased motorised mobility further facilitated by the focus on infrastructure leads to socially unacceptably high casualty and injury figures. The Commission for Global Road Safety headed by Lord Robinson cites a low political priority of road safety in low and middle income countries, which includes many emerging economies. It seems many politicians and bureaucrats see extending and widening a road network as an investment benefitting economic development, whereas improving the safety of it is seen as cost. The World Bank also stresses infrastructure improvement, capacity building to address systemic weaknesses and attention to vulnerable road users as key policies to improve road safety in low and middle income countries. Low cost measures which are known to be very effective include speed humps, zebra crossings, helmets and effectively separating fast and slow traffic. Road safety in many emerging economies could benefit from implementing such value-for-money measures.

The huge human and material losses should ethically justify politicians’ attention at an earlier stage, but they also make economic sense. Road safety losses are estimated at up to 5% of GDP in some low income countries. Still, road safety is not an election winner and it is next to impossible to score electorally by
vowing to improve road safety by increasing automated enforcement. Some politicians find that backing higher speed limits (for some reason equated with mobility) and reducing traffic jams, makes electorally more sense than backing road safety and effective enforcement. However, there are objective reasons for politicians to advocate and promote more effective enforcement. The connection between automated enforcement and the benefits to road safety is tested and confirmed in many academic publications. The Economist stated 'The cost of the cameras was repaid fivefold within a year in accident reduction and savings in medical treatment.' Moreover, lower speeds reduce pollution, noise levels, fuel consumption and thus add to the quality of life.

Automated enforcement requires funding i.e. considerable investment in human resources, equipment, systems and publicity, often scarce items in many emerging economies. It also needs amendments to several laws, involving complex negotiations between several ministries and other government bodies. Since political attention for road safety and automated enforcement does not come naturally it needs constant publicity and advocacy to create awareness and strong political and public support. In turn, this should motivate voters and thus politicians to further improve road safety, which often happens in high income countries, especially at a community level e.g. due to child safety and noise and pollution concerns.

France remains one of the best recent examples of the positive effects that strong political support can have on road safety. Remarkable progress has been made since 2002, a landmark year in French road safety policy. In the wake of a personal statement by President Jacques Chirac, the Interdepartmental Road Safety Committee (CISR) adopted a comprehensive plan in December 2002 to install a nationwide network of automatic speed enforcement systems and to fully automate the enforcement chain for driving offences, in particular for speeding offences. Effective curtailment of speeding by means of increased mobile and in-vehicle police enforcement, the nationwide enforcement camera project (roughly 4,150 fixed and mobile speed cameras in 2013), the efficient processing of the violations notices and the effective fine collection process is believed to be the principal reason for the considerable drop in the number of road deaths and injuries which was the French government’s objective in 2002. Other road safety risks such as drunk driving were also successfully addressed. This increased enforcement regime effectively changed the driving mentality of the French. The 2013 IRTAD report states that between 2002 and 2010 the average speed in France decreased by 10% and the speed violation rate decreased from 60% in 2002 to 33% in 2010. The report estimates that this contributed to saving 11,000 lives between 2003 and 2010. The successful French enforcement strategy is described in detail in publications of Mr. Laurent Carnis of IFSTTAR.

2.5. Publicity and advocacy to promote awareness, public and political support

In many countries strict enforcement, often with lacking publicity, may create a serious backlash by the public, the electorate and in various media. Examples of this are well-known in e.g. Germany, the UK and the Netherlands. The UK therefore uses detailed documentation on criteria for the location, operation, visibility and signage announcing speed cameras. Automated enforcement as a standalone activity runs a serious risk of being seen as a tax, revenue generator or a limit on freedom. This is actively encouraged by various media e.g. by reports on the massive amount of collected traffic fines. The fact that such revenues often benefit the ministry of finance or the general municipal account does not help. Directly funding road safety improvement projects with traffic fines collected from violators would create sustainable model which stifles the often abused tax and revenue collection argument mentioned above.

Few people object to enforcement in their own neighbourhood and in front of the school of their children, the YIMBY (Yes In My Back Yard) effect. However, further away from home, in the neighbourhoods of others, e.g. while trying to be in time for a meeting, the mood changes and a negative perception towards enforcement often takes over.

Continuous communication on enforcement benefits by means of publicity, education and advocacy to create better road safety awareness and more public and political support for enforcement is essential for its long term success. Regular publicity campaigns about the reasons for and results of enforcement programmes are a crucial part of any well-balanced road safety strategy. Governments starting with automatic enforcement need to take notice of the concept ‘no enforcement without publicity’. Once a negative public perception against enforcement takes hold, it will be hard to change this. It is therefore better get things right from the start.

3. THE ENFORCEMENT CHAIN

Enforcement works best when the violator is notified quickly of a violation and if the punishment, mostly the payment of a fine, is perceived as high enough to act as a strong deterrent. Administratively fine
collection can be a difficult and laborious process if the violator is not willing to pay. Therefore, it has to be absolutely clear to the violator that 1) a true violation took place, 2) there is no escape from the issued fine, and finally, that the penalty will continue to increase with payment delays. Moreover, it has to be obvious that eventually, any non-paying violator will be ordered to appear before a judge at the end of the enforcement chain. The public perception of successful court challenges has to be very low to discourage future challenges. Once in court, it also has to be clear that the escalated fines will be collected from the violator by whatever legal means possible.

News of an ineffective enforcement chain travels fast. If violators can afford to skip punishment, the number of violations will increase rapidly, enforcement loses its effect and road safety suffers. Apart from this issue, ineffectiveness and inefficiencies can appear in several other links of the enforcement chain often with negative effects on road safety. It is therefore important to analyse each link of this chain for potential bottlenecks. In this respect, emerging economies starting with automated traffic enforcement, have the benefit of leaning from the experiences of other countries.

The automated enforcement chain consists of the following links, which will be dealt with in the paragraphs below.

| 1. Detect  | 7. Process evidence, issue and send ticket |
| 2. Measure | 8. Receipt of ticket |
| 3. Decide on violation | 9. Provide evidence upon violator's request |
| 4. Register | 10. Collect fine |
| 5. Transfer | 11. Remind violating party |
| 6. Store evidence | 12. Court |

### 3.1 Detect

A high detection rate is a key item at the start of the enforcement chain. Identifying all passing vehicles is important since only then all potentially speeding vehicles can be caught. If only a low percentage of vehicles and thus violators are detected, some violators will escape. Feelings of injustice may then arise, that could affect the public support for enforcement. Systems with high detection rates are therefore required.

All detection methods have their advantages and disadvantages. High detection rates are possible with reliable and durable detection methods such as inductive loops or radar. If installed properly (loops) or mounted sufficiently high (radar), the overall disadvantages of these detection methods are quite limited. Although accurate, other methods such as video and piezo, laser and low mounted radar all suffer from some disadvantages due to one or more of the following issues: sensitivity lighting conditions, weather (fog, snow, rain, etc.), occlusion (blockage of a violating vehicle by another vehicle), soiling by precipitation and dirt from passing vehicles, increased wear and tear, high maintenance intensity and sensitivity to vandalism and damage. This reduces detection rates and thus reliability and legal equality.

### 3.2 Measure

After detection of a vehicle its speed needs to be measured. Obviously, this needs to be done correctly with a legally pre-defined accuracy (ref. §2.2 – type approval and calibration). It should be noted that the increasingly popular average speed enforcement systems (section control) calculate the speed based on accurate distance and time measurement and not by measuring spot speeds. Measurement is not relevant for red light enforcement. Detection of a passing vehicle during a red light phase is crucial here. This can be observed visually since both the position of the vehicle and the red traffic light can be seen in images and/or video.

### 3.3 Decide on violation

If a vehicle is measured exceeding a legally set speed limit this should result in a violation. Deciding on a violation is based on the comparison of two speed values by the enforcement camera i.e. the speed limit and the registered speed. Also here all violating vehicles should be treated in the same way. In case of a false negative, when enforcement equipment misses or fails to decide on speeding vehicles this will result in legal inequality. On the other hand, the same applies to false positives, when vehicles were registered as speeding, but were not. Implementing proper homologation, verification and calibration procedures will prevent these issues.
Concurrent violations can also be handled with the latest tracking radar technology and the higher data processing capacity of the most recent enforcement cameras. This means that accurate decisions accompanied by solid evidence can be taken e.g. of three vehicles speeding or going through a red light at the same trigger point at an intersection.

3.4. Register

After a positive decision on a violation, the image/video and data for that violation need to be registered immediately in a correct, secure and unchangeable way. When properly registering evidence data the use of cryptography is vital. Cryptography includes encryption, authentication and integrity. This allows for respectively 1) multiple reads only by authorised personnel (encryption), 2) data originating from the right source (authentication) and 3) no tampering with data by anyone (integrity). Records of non-violating vehicles need to be discarded, but depending on the country may also be kept longer e.g. for security or criminal investigations. Here a related issue comes up. How long can data of non-violating vehicles be kept by the violation camera? In light of privacy and security, which are often conflicting in terms of storage rights, such issues need to be legally defined.

In Germany a privacy issue prevents the implementation of average speed enforcement technology. This is based on the argument that data of innocent drivers cannot be registered, which means data registered at the first or entry camera of a section control system would violate the strict German privacy regulations since it is not know if a driver passing this camera is going to violate the speed. This can only be decided by combining the data of both cameras.

Often the license plate data from the registered image file are already processed and read in the enforcement camera by ANPR software and are digitally included in the evidence file. The ANPR data from an image include a value indicating the confidence level which specifies the certainty of the reading of a license plate. Confidence levels below a predetermined threshold will need additional processing, and may require a manual check which is costly and reduces operational efficiency. In France and the Netherlands, with fully automated processing from the initial violation registration to the issuance of a citation, a high ‘autoratio’ requirement is crucial. An autoratio of e.g. 90%, means that more than 90% of licence plates of the violating vehicles need to be read and processed automatically. Within this 90% less than 1 licence plate of 10,000 vehicles can be read erroneously. Such requirements put high demands on the readability of license plates, image quality of the enforcement camera and the ANPR software and processing. Governments aiming for processing efficiency should require equipment standards with high detection and read ratios and with low error ratios.

In owner liability countries license plate quality and readability affect the efficiency of automated violation processing. The clarity, uniformity and readability of a license plate affect the quality of the registered evidence. For instance large black letters on reflective white or yellow plates with a predictable uniform syntax and font get the highest ANPR rates. In owner liability countries this will cut processing costs significantly. Some countries (e.g. South-Korea and the Netherlands) have changed the license plate format, material, font and/or syntax to accommodate for this. The AAMVA (Association of American Motor Vehicle Administrators) issued a report with detailed recommendations on various aspects of license plate design. This benefits readability and thus enforcement efficacy and homeland security.

3.5. Transfer

After registration the evidence data need to be transferred from the enforcement camera to a central server which, depending on the organisation, can be located with the police, municipality, central or regional government organisation or even with a private company. Transfer of these data files should be subject to the above mentioned cryptography conditions. Such data can be transferred by means of a fixed data line, WiFi or 3G or 4G broadband connection. Depending on the authorised procedures, some countries opt for manually exchanging data storage devices (e.g. hard disks, memory cards or USB sticks) similar to exchanging wet film cartridges with analogue enforcement cameras. This obviously adds to processing costs. Moreover, such storage devices may get damaged or lost.

3.6. Storage

Violation evidence data are transferred to a secure data storage location where they need to be kept for longer term storage (also ref. 3.4.) to issue citations but also for future reference by either the violator, police, public prosecutor or judge. Such data need to be properly backed up or mirrored at other locations to
be secure in case of calamities. In line with local legal requirements a clear decision needs to be made on how long digital evidence files of traffic violations need to be kept and stored.

3.7. Process evidence, issue and send ticket

The evidence, which consists of one or two images (increasingly also video) and violation data, requires further processing in the back office to prepare tickets for issuing. There are considerable variations in the operations and functionalities of back offices depending on the legal framework and process architecture. License plates in violation images may need to be read and ANPR processed if they have not been processed already in the violation camera. Depending on the process, license plate data may need to be keyed in or confirmed visually by an authorised person. In this case the error rate of this manual procedure is considerably higher than that of automated ANPR processing.

Most driver liability countries need to identify the driver in the image and have to process all tickets manually. Lighting conditions of the license plates and drivers faces are quite different and need to be adjusted to produce credible evidence. Due to these requirements prosecutability rates of driver liability countries are considerably lower than of owner liability countries. The opposite applies to processing costs per ticket. However, new technology may allow for more automated processing of front photography images in driver liability jurisdictions.

Matching license plates with the owner’s addresses by accessing the vehicle registration database and matching the violation with a fine or penalty are key processes taking place in the back office. Several countries struggle to build and maintain an accessible, correct and up to date vehicle registration database. If a vehicle is sold and gets a new owner at say 15:46 on a given day, it needs to be registered as such. Inaccuracies in this database will result in fines for the wrong owner or driver which in turn affects public support for enforcement. When the owner’s address is found and the violation data matched with the legally set fine for the violation in question the citation can be issued and sent. Some countries which lack accuracy of postal addresses may opt for violation notification by SMS text messages sent to mobile phones.

As mentioned above a combination of owner liability, administrative law, good license plates, high quality enforcement cameras and effective ANPR software allow countries like France and the Netherlands to annually process millions of violations from automated enforcement systems with limited or no human intervention from one national citation processing and fine collection centre. However, when not managed properly huge volumes of evidence files from cameras can also create major operational bottlenecks. These can affect or even shut down enforcement programmes and may thus hamper road safety. Various media in Belgium reported recently that their new average speed control systems had to be turned off at certain times since more violations were registered than could be handled operationally. This resulted in a backlog of roughly 23,000 unprocessed violations. Backlogs which continue to grow tend to run the risk of being dismissed, which sets a serious precedent, creates expectations among drivers for more dismissals and affects the credibility of road safety enforcement.

3.8. Receipt of ticket

After sending out a citation by means of a letter it needs to be received by the owner of the violating vehicle. This all sounds quite logical but governments need to arrange that ‘not receiving’ such notice or letter will not be an acceptable reason for ignoring the violation notice and thus for crippling this link of the enforcement chain. Depending on the quality of the postal delivery, registered mail may be considered but in most countries regular mail is used. However, this means a legal and procedural arrangement needs to be made which implies that sending a violation notice implies receipt of the same. This again stresses the necessity of an accurate vehicle owner registration database obviously including the current owner’s addresses as an essential requirement for effective enforcement.

Research has shown that the earlier the driver is confronted with a violation the better the effect of enforcement is for correcting driving behaviour. This means governments in emerging economies need to set up efficient back office processing facilities. In owner liability countries technology allows for an almost immediate notice of a violation by means of an e-mail or SMS text message. This means e-mail addresses and mobile phone numbers need to be included in the vehicle registration database. In counties with unreliable postal delivery SMS violation notification could be a more reliable delivery method since most people driving cars will own mobile phones.

3.9. Provide evidence upon violator’s request
Many vehicle owners who receive a violation notification may want to obtain more information, i.e. see the evidence photo with the violation data such as speed, location, time, etc. Such information can be sent by mail or offered by means of internet access. In countries with driver liability and front photography the passenger side is blocked out for privacy reasons.

When providing violation evidence over the internet, other relevant information which further backs this evidence can also be offered to the violator. This may include data on the homologation, verification and calibration of the relevant enforcement equipment or anonymous credentials and training data of the police officer in question. After reviewing the evidence over the internet the violator may be given the option to select a fine payment or objection window.

A key aspect which should be presented to a violator is targeted publicity on why enforcement takes place, and more specifically, why on the violation location. For example: “The E37 road stretch where speeding with your vehicle was registered is speed enforced since 3 casualties, 4 injuries and 7 crashes occurred here in the past 5 years”. Such publicity also contributes to enforcement being seen as a road safety measure and not as a government revenue generator.

3.10. Collect fine

Similar to sending the citation, fine collection should be effectuated as early as possible to maximise the effect of enforcement as a road safety instrument. To encourage timely payment the citation should clearly specify the fine escalation scheme and collection process should the violator not settle the fine within the due date. Some countries (e.g. Germany) work with an initial warning or a transaction proposal with a relatively low fine for a minor violation which has to be paid quickly. Late payment initiates a higher fee and a more formal legal process.

Of the roughly 10.3 million fines issued in 2013 the Dutch Central Fine Collection Agency (CJIB) collected 97,5% of the fines within one year. In France the Centre National de Traitement (CNT), a similar centre in Rennes, collected 80% of the 4,5 million issued fines within 45 days in 2010. Most of the violators in France are paid over the internet.

3.11. Remind violating party

As part of an efficient fine collection process and to maintain the efficacy of the enforcement chain, payment reminders need to be sent automatically to overdue violators. In the Netherlands the traffic fine is increased by 50% with a first payment reminder if the initial due date of eight weeks is missed. A second reminder doubles the initial fine if the first reminder did not result in payment. If a second reminder is not effective coercion methods will be implemented. This out of court coercion process should be well-defined legally and procedurally. Coercion methods in EU countries include: using a bailiff, withdrawing fines directly from bank accounts or from the salary via the employer (Attachment of Earnings Order), seizing of tax credits, impounding vehicles, invalidating driving licenses, etc. In several countries vehicles owned by drivers with overdue fines can only pass their periodic motor vehicle inspection or drivers license renewal if all traffic fines are paid. Forced fine payment can also occur at police road blocks or during border or airport identification checks when going or returning from a trip abroad. Police cars may have ANPR scanning devices which, while on patrol, will automatically check for various violations. These could include overdue violations, car insurance, stolen vehicles, vehicle inspection compliance, etc.

3.12. Court

To conclude the automated enforcement chain as the final link, and if all the above fails, the violator should know that a judge will ultimately cast a final verdict at the end of the chain. The public prosecutor and judge need to be supported in their judgement by type approval, verification and calibration certificates for enforcement equipment in question, issued by an independent, often government related organisation, as referred to earlier. In order to prevent backlogs and subsequent acquittals due to court overload, the preceding links of the automated enforcement chain should be organised and managed in such a way that the number of violation cases ending up in court should be kept to the absolute minimum.

Successfully implementing automated enforcement needs efficiency and efficacy of the entire enforcement chain and compliance with essential legal, administrative and operational preconditions. However, enforcement can never be effective as a stand-alone activity. Only in concert with continuous communication, education, publicity and advocacy to promote public understanding and to maintain political support can automated enforcement realise to its ultimate purpose: improving road safety.
4. Conclusion

Emerging countries starting with or intensifying automatic enforcement in their jurisdiction should carefully consider the full scope and implications of their project. It seems quite simple and straightforward. However, the automatic enforcement chain is full of pitfalls which could lead to a sub-optimal or even wasted investment in enforcement equipment and other resources that would not improve road safety. Carefully analysing the various guidelines, requirements and processes of each step in the automatic enforcement chain is essential. The outcome of this analysis may result in time consuming changes and adjustments e.g. in laws, guidelines, organisations and processes. Special attention should be paid to political and administrative support, license plates and owner and driver registration databases, legal procedures, hard & software integrity, certification, evidence and ticket processing and fine collection and fine re-investment in road safety. Only a properly working automatic enforcement chain together with effective and continued publicity about its background and results can deliver optimal enforcement benefits and thus advance further improvements in road safety in emerging economies.

REFERENCES


The safety impact of automated enforcement in Malaysia

One of the nine strategies in the Road Safety Plan Malaysia 2006-2010 is to utilize state of the art technologies to reduce human error for more effective enforcement. Therefore the government of Malaysia has introduced an electronic enforcement programme called Automated Enforcement System (AES) in 2012. National traffic crashes in 2011 shows that about 23% of fatal crashes is related to speeding, while for the past five years, the number of crashes at signalised intersections in Malaysia has shown an upward trend, and this resulted in 207 fatalities and 706 injuries in 2011. Thus, the AES programme focus on the speeding and red light running offenses. The programme kicks off as a pilot programme with 10 locations for speeding and 4 locations for red light running. Awareness and advocacy activities were carried out in order to educate the road users prior to commencement of the AES programme. Several studies were carried out to evaluate the safety impact of this programme. The studies were related to observation of compliance with speed limits and traffic light as well as the perception and acceptance of road users towards the AES implementation. The studies were carried out before and after the programme implementation. The speed limit compliance at 10 locations with AES camera was 51.1% before the AES implementation and increase to 91.2% after the AES implementation. An odd ratio analysis reveals that drivers tend to not comply with the speed limit 11.3 times more for before AES installation compared to after AES installation. The study on public perception and acceptance of the AES programme indicates that there is a positive change among drivers in terms of the speed limit and traffic light compliance after the implementation of AES camera at the study locations. Drivers were found to be more careful when approaching the AES camera locations. The study also shows that the AES camera affected the driver compliance with the speed limit and traffic light, although they may not pass through any AES camera sites. Generally, these studies found that AES implementation has a positive safety impact to the road users. It is therefore recommended that the programme to be continued in order to lower down the road deaths in this country.
The safety impact of automated enforcement in Malaysia
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1 INTRODUCTION

The fatality figure due to road crashes in Malaysia fluctuates at around 6,000 deaths a year and showing an upward trend since the year 2000 as shown in Figure 1. In 2014, the road fatalities were 6,744 results from 476,196 road traffic crashes. During the 14 year period, the peak of road traffic deaths was in 2012 with 6917 deaths. On average, there are 18 road traffic deaths and 1,305 road traffic crashes daily. The figure is alarming and the government is adamant to reduce it to save more lives. Road Safety Plan of Malaysia 2006 – 2010 and Road Safety Plan of Malaysia 2014 – 2020 outlines the strategic framework to deliver the long term vision that was set for road safety in Malaysia. In both plans, one of the strategies is to utilize state of the art technologies to reduce human error for more effective enforcement. Therefore the government of Malaysia has introduced an electronic enforcement programme called Automated Enforcement System (AES) in 2012. Electronic camera enforcement could serve many functions including bus lane, overloading vehicles, multilane free flow, congestion pricing and tailgating, speed and red light running violation.

National traffic crashes in 2011 shows that about 23% of fatal crashes is related to speeding, while for the past five years, the number of crashes at signalised intersections in Malaysia has shown an upward trend, and this resulted in 207 fatalities and 706 injuries in 2011. With this evidence the AES programme in Malaysia only focus to speeding and red light running offenses. The programme starts off as a pilot programme with 10 locations for speeding and 4 locations for red light running. The programme used fixed type and mobile type camera to record both offenses. However, the mobile type camera is only used for speeding offenses. For speeding there are 6 locations with a fixed camera and the rest 4 locations using mobile cameras. Fixed cameras are mounted in boxes at fixed locations and can continuously monitor traffic speeds and digitally connected to an electronic system. While mobile camera operations are mounted on tripods by the side of the road and enforcement officer is present during the operation. As compared to some practice in other countries, here the mobile camera acts similar to fixed camera where the locations are fixed at the same locations each time the mobile camera in operation.

Based on Sharifah Allyana et al. (2013), the locations are determined scientifically for speeding and red light running crashes. The AES camera placement was based on historical crash information obtained through the Royal Malaysia Police (RMP) national crash database. Publicized police enforcement has been shown to reduce vehicle travel speeds and crashes, according to Stuster (1995). However, enforcement agencies do not have sufficient resources to mount effective enforcement programs. The number of Vehicle Miles Travelled (VMT) increased by 23%, but law officers grew by only 12% (FHA 2007). Locally, a report by MIROS on Ops Bersepadu Chinese New Year 2007 concluded that the concentrated enforcement activity has resulted in fewer deaths compared to normal days and therefore should be continued throughout the year. Each camera installed together with the AES signboard approaching
to the camera location. Awareness and advocacy activities were carried out in order to educate the road users prior to commencement of the AES programme. Hence, with this, it is clear that this programme is using overt enforcement approach.

Although the programme focus on speed and red light camera, however this paper will mainly focus on the automated speed camera. The paper's objective is to see the safety effect of using automated speed camera in relation to speed profile before and after the programme implementation. Speed camera enforcement is an important road safety initiative that has proven road safety benefits and is a commonly employed method of speed enforcement in many best practice road safety jurisdictions throughout the world. Speed enforcement helps to reduce the proportion of drivers who exceed the speed limit on our roads, which in turn reduces the risk of being involved in a fatal or injury crash and the severity of outcomes in the event of a crash.

2 LITERATURE REVIEW

Studies have shown that the implementation of electronic enforcement using the camera was proven to reduce the speed profile and speed related accidents in developed countries mainly in the United Kingdom, the U.S.A. and Australia. An evaluation study by Richard A. Retting in Montgomery County, Maryland showed large and significant reductions in speeding 6 months after the implementation of Maryland’s first speed camera program. A Four-year Evaluation report by College London & PA Consulting shows that the number of vehicles exceeding the speed limit at fixed camera sites fell by 70%, while the number of people killed or seriously injured fell by 42%. There was also a 32% reduction in the number of children killed and seriously injured whereas the number of pedestrian killed or seriously injured also reduced by 29% at camera sites.

In Norway, the automatic speed enforcement by means of speed cameras was first introduced in 1988. Elvik (1997) performed an evaluation study to see the effects of automatic speed enforcement on accidents using a before-and-after study. The study controlled for general trends in the number of accidents and regression-to-the-mean. The study reveals there were 20% statistically significant reduction in the number of injury accidents and 12% reduction for property-damage-only accidents. However, this change was not statistically significant at the 5% level of significance. The level of compliance with the official warrant has varied effects of the automatic speed enforcement on accidents. The warrants refer to an accident rate (accidents/vehicle km) and accident density (accidents/km of road). In road sections that complied with both warrants, a decline of 26% was observed in an injury accident. While the injury accidents declined by 5% if any of the road sections did not comply with any of the warrants.

An evaluation report on the fixed digital speed camera program in NSW by ARRB Group in 2005 reported overall crashes fell by almost 20% along road segments with speed camera that had demonstrated high crash risk. Fatal crashes were drastically reduced by nearly 90%, casualty crashes by 23% and injury crashes by 20% along the speed camera segments. From the speed data, approximately 6km/h reduction in mean speed was recorded at the speed camera site after 12 months and 24 months of the implementation date. The report also revealed the percentage of vehicles exceeding the speed limit reduces by about 70% to 90% along the camera sites.

Retting R.A. evaluate the effectiveness of the program by measuring the mean speed of the case site and also by using telephone survey to assess public awareness and attitude toward the camera enforcement program. Both study traffic speed measurements and telephone survey were carried out 6 months in advance of camera enforcement and 6 months following the implementation of the program. Chen G., et al (2000), evaluated the speed and traffic safety effects of the photo radar program in British Columbia (BC) after 1 year of full operation. Traffic speed data were collected from the photo radar units and from induction loops installed across the province. Traffic collision and injury data were obtained from police investigation reports and from BC ambulance service record. The study employed a number of analytical frameworks, including simple before and after comparison, time-series cross-sectional analysis, and interrupted time series analysis.

3 METHODOLOGY

The evaluation was carried out by using before-and-after study with three indicators to determine the effectiveness of automated speed camera. The three indicators are 85th percentile speed profile, average speed and speed limit compliance level. The study was carried out independently from the said programme but at the same location as the speed camera. Data was collected a month before the programme started and about five months after it was implemented. And subsequently data were collected about two years after to programme to see if the effect remains the same. The spot speed study was used to obtain the speed data. Data collection was carried out during off peak period. Data was also collected separately on weekdays and weekends to see the difference pattern. The data were collected in one hour duration during the off peak hour.
A spot speed study is designed to measure the speed characteristics of a specific location under the traffic and environmental conditions prevailing at the time of study. Generally there are three technology method can be used to determine speed which is; hand held, in-road or out of road technologies. For handheld technologies the equipment is manually operated and minimum data requirements must be met to ensure quality of data while efforts must also be made to reduce bias. Examples of this technology are radar and LiDAR. Pneumatic Road Tubes, Magnetic Sensors and Inductive Loops are some example of in-road technologies. These technologies usually cause disruption of traffic flow during installation and maintenance but are suitable for long term duration of data collection. Meanwhile, out-of road technology will cause limited or no disruption of traveled way during the data collection period. Microwave, Ultrasonic, Acoustic, and Infrared are some examples of out-of-road technologies. This study was carried out using the out-of-road technology with a device called Smart Sensor. The Smart Sensor uses micro wave to operate.

4 RESULTS

Generally, from the 10 locations, there are 2 locations with 100 km/h speed limit, 4 locations with 90 km/h speed limit, 3 locations with 80 km/h speed limit and 1 location with 70 km/h speed limit as shown in Table 1. In terms of carriageway type, there are 3 locations with single carriageway and the rest are dual carriageway.

<table>
<thead>
<tr>
<th>Location</th>
<th>Speed Limit (km/h)</th>
<th>Road Type</th>
<th>Carriageway Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sungkai</td>
<td>90</td>
<td>Federal Road</td>
<td>Single</td>
</tr>
<tr>
<td>Slim River</td>
<td>110</td>
<td>Expressway</td>
<td>Dual</td>
</tr>
<tr>
<td>Taiping</td>
<td>110</td>
<td>Expressway</td>
<td>Dual</td>
</tr>
<tr>
<td>Kajang</td>
<td>90</td>
<td>Expressway</td>
<td>Dual</td>
</tr>
<tr>
<td>SKVE</td>
<td>80</td>
<td>Expressway</td>
<td>Dual</td>
</tr>
<tr>
<td>Leboh Sentosa</td>
<td>70</td>
<td>Municipal Road</td>
<td>Dual</td>
</tr>
<tr>
<td>Persiaran Timur</td>
<td>80</td>
<td>Municipal Road</td>
<td>Dual</td>
</tr>
<tr>
<td>Teluk Intan</td>
<td>90</td>
<td>Federal Road</td>
<td>Single</td>
</tr>
<tr>
<td>Ipoh-Butterworth</td>
<td>90</td>
<td>Federal Road</td>
<td>Single</td>
</tr>
<tr>
<td>Sg Besi</td>
<td>80</td>
<td>Expressway</td>
<td>Dual</td>
</tr>
</tbody>
</table>

Table 2 shows the 85th percentile speed before and after the camera installation. An 85th percentile speed is a speed at or below which 85% of people drive at any given location under good weather and visibility conditions and may be considered as the maximum safe speed for that location. From the table it is shown that only 4 locations Sungkai and Taiping for fixed camera and; Teluk Intan and Ipoh-Butterworth for mobile camera recorded lower 85th percentile speed limit on weekdays. Meanwhile, on weekends, the 85th percentile speed still remains high where only 3 locations recorded lower than the posted speed.

Six months after the AES programme all locations show a reduction in 85th percentile speed on weekdays except Taiping. Although the speed at Slim River reduce by 7.7 km/h after the programme, but it is still slightly higher than the posted speed limit. Kajang and SKVE recorded the highest reduction in the speed value with 26.5 km/h and 17.7 km/h respectively in the six month period. After 2 years of implementation the data show that the speed at all locations are lower as compared to the before period. Slim River continue to record lower 85th percentile speed than the posted speed limit after 2 years implementation. Unfortunately Persiaran Timur shows higher speed than the posted speed limit after the 2 year period.

Meanwhile the analysis on the weekends data 6 months after the programme implementation demonstrate that all locations except Sg Besi has lower speed that the before period. Positive effect on the 85th percentile speed continue to be observed after 2 years implementation which the speed value is lower than the before period except for one location (Teluk Intan). The speed at Teluk Intan and Ipoh-Butterworth consistently lower than the posted limit during the study period. The 85th Lebuh Sentosa and Sg Besi on the other hand shows higher speed as compared to the posted speed limit on weekdays throughout the study period.
Table 2. 85th percentile speed before and after camera installation

<table>
<thead>
<tr>
<th>Location</th>
<th>Speed Limit (km/h)</th>
<th>Camera Type</th>
<th>Weekdays Before (km/h)</th>
<th>After 6 months (km/h)</th>
<th>After 2 years (km/h)</th>
<th>Weekends Before (km/h)</th>
<th>After 6 months (km/h)</th>
<th>After 2 years (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sungkai</td>
<td>90</td>
<td>Fixed</td>
<td>82.7</td>
<td>75.1</td>
<td>74.4</td>
<td>83.5</td>
<td>73.1</td>
<td>77.0</td>
</tr>
<tr>
<td>Slim River</td>
<td>110</td>
<td>Fixed</td>
<td>118.8</td>
<td>111.1</td>
<td>105.5</td>
<td>123.6</td>
<td>112.1</td>
<td>105.3</td>
</tr>
<tr>
<td>Taiping</td>
<td>110</td>
<td>Fixed</td>
<td>104.4</td>
<td>104.4</td>
<td>102.6</td>
<td>114.8</td>
<td>101.3</td>
<td>103.3</td>
</tr>
<tr>
<td>Kajang</td>
<td>90</td>
<td>Fixed</td>
<td>113.0</td>
<td>86.6</td>
<td>80.7</td>
<td>95.9</td>
<td>88.2</td>
<td>80.2</td>
</tr>
<tr>
<td>SKVE</td>
<td>80</td>
<td>Fixed</td>
<td>97.5</td>
<td>79.8</td>
<td>74.9</td>
<td>98.6</td>
<td>81.0</td>
<td>76.0</td>
</tr>
<tr>
<td>Leboh Sentosa</td>
<td>70</td>
<td>Fixed</td>
<td>89.1</td>
<td>78.3</td>
<td>75.1</td>
<td>82.7</td>
<td>70.0</td>
<td>69.6</td>
</tr>
<tr>
<td>Persiaran Timur</td>
<td>80</td>
<td>Mobile</td>
<td>99.3</td>
<td>82.5</td>
<td>90.3</td>
<td>101.1</td>
<td>91.2</td>
<td>87.9</td>
</tr>
<tr>
<td>Teluk Intan</td>
<td>90</td>
<td>Mobile</td>
<td>75.3</td>
<td>74.1</td>
<td>73.7</td>
<td>77.5</td>
<td>77.1</td>
<td>77.9</td>
</tr>
<tr>
<td>Ipoh-Butterworth</td>
<td>90</td>
<td>Mobile</td>
<td>68.0</td>
<td>60.6</td>
<td>68.2</td>
<td>68.9</td>
<td>62.5</td>
<td>67.8</td>
</tr>
<tr>
<td>Sg Besi</td>
<td>80</td>
<td>Mobile</td>
<td>90.0</td>
<td>82.0</td>
<td>83.5</td>
<td>81.9</td>
<td>81.9</td>
<td>78.0</td>
</tr>
</tbody>
</table>

The compliance with the speed limit at all study locations is shown in Table 3. Before the speed camera installation for fixed cameras, only Sungkai have more than 85% compliance. On weekdays, the compliance with speed limit was the lowest at Kajang (29.7%). For mobile camera, the compliance level was the lowest at Persiaran Timur 32.9% on weekdays and 33.5% on weekends. After 6 months of the automated speed programme, all fixed camera locations recorded compliance level more than 85%, except Leboh Sentosa and 2 years later all fixed camera locations recorded 89% and above compliance to speed limit. The highest increase in speed limit compliance level was at Kajang with more than 60% jump after a 2 year period. This is due to the low level speed limit compliance at the location before the installation.

In contrast with the pattern on weekdays, before the AES installation, none of the locations had speed limit compliance more than 85%. On weekends, the compliance with the speed limit range between 40.9% and 81.7% of all six fixed camera locations. The lowest speed limit compliance was observed at Kajang and the highest at Sungkai before installation period. All six locations showed higher compliant level to speed limit on weekends after the AES implementation, with an average compliance of 90%. Sungkai recorded the highest speed limit compliance with 96.1%, while Slim River recorded the lowest with 77.5% after 6 months of the programme.

For mobile camera at Sungai Besi the compliance level are always below 82% throughout the study period. Similar to the 85th percentile analysis, Teluk Intan and Ipoh-Butterworth has almost 100% compliance with speed limits during all the 3 phases of the study period.

Table 3. Compliance with speed limit before and after implementation

<table>
<thead>
<tr>
<th>Location</th>
<th>Speed Limit (km/h)</th>
<th>Camera Type</th>
<th>Weekdays Before (%)</th>
<th>After 6 months (%)</th>
<th>After 2 years (%)</th>
<th>Weekdays Before (%)</th>
<th>After 6 months (%)</th>
<th>After 2 years (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sungkai</td>
<td>90</td>
<td>Fixed</td>
<td>86.3</td>
<td>98.0</td>
<td>96.7</td>
<td>81.7</td>
<td>96.1</td>
<td>95.8</td>
</tr>
<tr>
<td>Slim River</td>
<td>110</td>
<td>Fixed</td>
<td>74.2</td>
<td>86.1</td>
<td>91.3</td>
<td>56.1</td>
<td>77.5</td>
<td>90.3</td>
</tr>
<tr>
<td>Taiping</td>
<td>110</td>
<td>Fixed</td>
<td>82.4</td>
<td>94.2</td>
<td>95.6</td>
<td>79.2</td>
<td>94.1</td>
<td>93.0</td>
</tr>
<tr>
<td>Kajang</td>
<td>90</td>
<td>Fixed</td>
<td>29.7</td>
<td>93.4</td>
<td>96.3</td>
<td>72.1</td>
<td>92.7</td>
<td>96.9</td>
</tr>
<tr>
<td>SKVE</td>
<td>80</td>
<td>Fixed</td>
<td>48.1</td>
<td>94.7</td>
<td>94.7</td>
<td>40.9</td>
<td>90.3</td>
<td>95.0</td>
</tr>
<tr>
<td>Leboh Sentosa</td>
<td>70</td>
<td>Fixed</td>
<td>57.1</td>
<td>80.5</td>
<td>89.9</td>
<td>74.5</td>
<td>90.2</td>
<td>90.3</td>
</tr>
<tr>
<td>Persiaran Timur</td>
<td>80</td>
<td>Mobile</td>
<td>32.9</td>
<td>85.3</td>
<td>64.8</td>
<td>33.5</td>
<td>75.1</td>
<td>78.6</td>
</tr>
<tr>
<td>Teluk Intan</td>
<td>90</td>
<td>Mobile</td>
<td>96.4</td>
<td>98.7</td>
<td>98.1</td>
<td>95.8</td>
<td>98.2</td>
<td>97.1</td>
</tr>
<tr>
<td>Ipoh-Butterworth</td>
<td>90</td>
<td>Mobile</td>
<td>99.5</td>
<td>100.0</td>
<td>100.0</td>
<td>99.0</td>
<td>99.7</td>
<td>99.7</td>
</tr>
<tr>
<td>Sg Besi</td>
<td>80</td>
<td>Mobile</td>
<td>61.0</td>
<td>74.2</td>
<td>78.6</td>
<td>71.3</td>
<td>72.6</td>
<td>81.6</td>
</tr>
</tbody>
</table>
Table 4 shows the odds ratio after 6 months and 2 years of the AES programme in relation with before the period for fixed cameras. In Kajang, drivers tend to not comply with the speed limit 33.506 times more for before AES installation compared to after 6 months of AES installation. In order to arrive at a conclusion, a Chi-square analysis was performed to investigate whether the increase in speed limit compliance in relation to the traffic volume before and after AES installation is significant. The result shows that the increase in speed limit compliance between the two periods is significant (p<0.05) at four locations, namely Slim River, Kajang, SKVE and Lebuh Sentosa on weekdays.

On weekends it was found that drivers tend not to comply with the speed limit 2.689 to 13.392 times more for before AES installation as compared to the after period. The chi square analysis on the weekend’s data shows that after AES installation the increase in speed limit compliance is statistically significant (p<0.05) at all study locations except Sungkai.

Table 4. Odds ratio after 6 months and 2 years implementation

<table>
<thead>
<tr>
<th>Location</th>
<th>Weekdays OR 6 months</th>
<th>Weekdays OR 2 years</th>
<th>Weekends OR 6 months</th>
<th>Weekends OR 2 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sungkai</td>
<td>7.610</td>
<td>4.671</td>
<td>5.459</td>
<td>5.095</td>
</tr>
<tr>
<td>Slim River</td>
<td>2.170</td>
<td>3.624</td>
<td>2.689</td>
<td>7.286</td>
</tr>
<tr>
<td>Taiping</td>
<td>3.496</td>
<td>4.677</td>
<td>4.166</td>
<td>3.531</td>
</tr>
<tr>
<td>Kajang</td>
<td>33.506</td>
<td>60.698</td>
<td>4.907</td>
<td>11.961</td>
</tr>
</tbody>
</table>

The study on public perception and acceptance of the AES programme indicates that there is a positive change among drivers in terms of the speed limit and traffic light compliance after the implementation of AES camera at the study locations. Drivers were found to be more careful when approaching the AES camera locations. The study also shows that the AES camera affected the driver compliance with the speed limit and traffic light, although they may not pass through any AES camera sites (Sharifah Allyana et al., 2014).

The perception of being caught study concluded that the majority of the respondents surveyed considered, there is less than 70% likelihood of being summonsed by the enforcement personnel for speeding before the implementation of AES. This means that the drivers felt that the odds of getting summonsed by law enforcement were not high even for speeding.

5 CONCLUSIONS

The study summarises the observation of road user’s attitude towards the posted speed limit. The three indicators used show that before the AES implementation, road users did not obey the posted speed limit. This practice holds true during weekdays and weekends. However the degree of non-compliance varied according to locations.

Generally, it can be observed that the mean speed after the AES installation are lower compared to those before. Similarly, before the AES installation, the 85th percentile speeds at all locations, except Sungkai, were higher than the posted speed limit during either weekends or weekdays. In terms of compliance with the speed limit, it can be concluded that the compliance level at low speed limit locations (70–90 km/h) was low compared to the 110 km/h speed zone, even before the installation period at the fixed camera locations. A statistical analysis was conducted and it proved that the increase in speed limit compliance is statistically significant at four locations on weekdays and five locations on weekends.

Speed profile alone is not sufficient to indicate the effectiveness of the program, thus accident and injury data from the police has to be obtained to support the evaluation study. Hence the future study supported with crash data will give more accurate evidence on the effectiveness of automated speed camera programme.

6 ACKNOWLEDGEMENTS

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EVALUATING DRIVER'S DISTRACTION FACTORS IN MOTORWAYS. A NATURALISTIC STUDY BASED ON DRIVER'S AND ROAD CHARACTERISTICS

 TRACK: E.2 Data Collection and Diagnosis

<table>
<thead>
<tr>
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<th>POSITION</th>
<th>ORGANIZATION</th>
<th>COUNTRY</th>
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<tbody>
<tr>
<td>MISOKEFALOU</td>
<td>Sessional Lecturer</td>
<td>University of Thessaly</td>
<td>Greece</td>
</tr>
<tr>
<td>CO-AUTHOR(S) (Capitalize Family Name)</td>
<td>POSITION</td>
<td>ORGANIZATION</td>
<td>COUNTRY</td>
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<tr>
<td>KOPELIAS</td>
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<tr>
<td>HALKIAS</td>
<td>Chief Executive Officer (Managing Director)</td>
<td>Attica Tollway Operations Authority &quot;Attikes Diadromes S.A.&quot;</td>
<td>Greece</td>
</tr>
<tr>
<td>ELIOU</td>
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<td>University of Thessaly</td>
<td>Greece</td>
</tr>
</tbody>
</table>

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KEYWORDS:
Driver's distraction, billboards, urban freeway, naturalistic study

ABSTRACT:
Over the last years, distracted driving possesses a leading position among accident causes and constitutes an increasing road safety problem with disastrous results. The present study deals with driver's distraction due to out-of-the-vehicle factors, as well as driver related factors, such as age, gender, driving experience etc. It covers the distraction of driver attention during driving due to external factors that are not related to the main task of driving, resulting in impairments to their attention and decision-making ability and hence their overall performance. Considering external factors as the most significant, we can group them in four categories: built roadway, situational entities, natural environment, and built environment. The fourth category is related to civil infrastructure and commercial land use, combined with high vehicle speeds. All these contribute to the setup of a very dangerous environment, which increases driver distraction and inattention. Through accurate research, solid results can emerge and contribute to enhanced traffic safety. In order to create the appropriate research basis, it is necessary to use as much reliable data as possible, such as exposure, focus group, survey and crash-based data, data relied on simulators. This research is based on a medium-scale experimental procedure which took place in three urban freeways in Greece, using a sample of 77 drivers. The distraction of driver attention is evaluated via a continuous recording of his/her gaze, which acts as the main indicator regarding driver performance. The main objective of this paper, which is the investigation of the existence of driver distraction due to out of the vehicle factors and especially advertisement signs, is met and the results reveal the presence of a dangerous interaction between driver’s attention and road elements. This study can be used as a tool towards the ban of roadside elements - not related to the execution of the driving task - that serve as potential causes of distraction. The results of this type of research procedures are very useful to prevent the forthcoming pressure for more billboards and trademarks on the roads, as well as to encourage the adaptation of more precise regulations relating to the road infrastructure, the placement of roadside elements, etc.
EVALUATING DRIVER’S DISTRACTION FACTORS IN MOTORWAYS. A NATURALISTIC STUDY BASED ON DRIVER’S AND ROAD CHARACTERISTICS

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I INTRODUCTION

Distraction of driver’s attention is a major road safety issue, while distracted driving possesses a leading position among accident causes. The main causes of distraction are classified into two categories: those coming from the interior of the vehicle and those from the external environment. Regarding the second category the sources of driver distraction can be grouped in four major categories: built roadway, situational entities, natural environment, and built environment (Horberry & Edquist, 2008).

Numerous studies have shown that external factors have significant impact in driving task. For instance an outside person, an object or an event is the main cause for 30% of the distraction generated accidents (Tasca, 2005). A review of several accident databases resulted that external distractors are responsible for 10% of all accidents (Wallace, 2003). In Young et al. (2009) simulator study there is a tentative suggestion that more crashes occur when billboards are present. Accident statistics in many countries confirm the participation of distraction as a cause of road accidents. For example, accident data from United States show that the number of people injured during a crash which caused due to distraction, was 515,000 or 22% of all injuries (NHTSA, 2009). Also the official statistics published by the Greek Traffic Police for the year 2014 show that 43 (5.8%) of the total of 747 fatal accidents were due to driver’s distraction while other causes or types, such as crash on roadside obstacle/equipment and mobile phone use, have a strong relationship with the distraction issue (Greek Traffic Police, 2015).

There is not a simple theory behind the distraction of driver’s attention during the implementation of the driving task. The analysis of the phenomenon has leaded the scientists to conclude that a multilevel procedure is activated each time the attention is distracted, depended on many factors (Lee et al., 2009). Distraction in all forms, may be visual, cognitive, biomechanical and auditory (Ranney et al., 2001). Many researchers have tried to define driver distraction and as a result the related literature contains a significant number of those definitions (Misokefalou, 2014). In the first International Conference on Distracted Driving (Hedlund et al., 2005) the scientific community agreed on a definition for distracted driving: “Distraction involves a diversion of attention from driving because the driver is temporarily focusing on an object, person, task, or event not related to driving, which reduces the driver’s awareness, decision-making, and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes”. The results of this phenomenon are detected in all drivers with various degrees of extension and appearance.

The detection of driver’s distraction can take place via an evaluation of the produced results which can be either crashes or near crashes, unnecessary speed changes, sudden loss of vehicle control and exit from the lane. Furthermore, distraction can be found via the detailed study of the driver’s glance during driving. The methods to achieve data collection are various and can be grouped into 3 three basic categories: a) studies based on accidents statistics b) experimental studies of driving performance c) studies of observation. Additionally, there are some kinds of methods that are not included in any of the previous categories but are often met at the bibliography such as Peripheral Detection Task method and Visual Occlusion method (Eliou & Misokefalou, 2009).

The selection of the appropriate method has been described in comparative studies which exam the advantages and the limitations of every method respectively, as well as the usefulness and necessity of results that each method produces. It is suggested that only after the completion of the examination of every available method, the researcher can choose the method he/she considers appropriate for his research (Young & Regan, 2007). A previous study (Eliou & Misokefalou, 2009) tried to objectively assess all the available
methods for this purpose. The writers concluded to the selection of the most appropriate method, mostly by rejecting some of them because of their serious disadvantages. The method considered one of the most appropriate, for this kind of studies, belongs in the observational-naturalistic category. These studies are taking place in the field, using equipped vehicles in order to record the driver’s eye movements and measure the frequency and the duration of the glances at every potential source of visual distraction. The distraction of driver attention is evaluated via a continuous recording of his/her gaze movement, which is the main indicator regarding driver performance.

The present study deals with driver’s distraction in motorways and investigates its existence which can be caused from several road entities – related or not to the main driving task - especially from advertisement signs. The experimental naturalistic data were collected by a total number of 77 drivers in three freeways in Greece with the use of Facelab machine, which is capable of making continuous data recording of driver’s gaze direction. Captiv software, compatible with FaceLab L2100, was used for the analysis of the results. This software analysed detailed data, produced by records of the number of glances at every selected element of the route, as well as the total time that the specific point (whereas point in the paper implies a selected road element) captured driver’s gaze.

2 METHOD

2.1 Experimental site

The experimental part of the research took place in 3 motorways in Greece. The study took place in motorways due to the high speeds that drivers develop on them - in contrast with local streets with traffic lights - which leads to more serious accidents. The first motorway (Site 1) was Attica Tollway (also named Attiki Odos), the ring road of Athens Metropolitan area. There were three routes under observation with a length of 19, 16.8 and 15 km respectively in which the speed limit is between 80-120km/h. The second motorway (Site 2) is Kifissos Avenue, which is the urban part of the National Road that connects the city of Athens with the Northern Greece. The route under observation in Kifissos Av. has a total length of 10 km and the speed limit was between 100 to 120km/h. The third motorway (Site 3) is the National Road between the city of Thessaloniki and the city of Giannitsa, in Northern Greece. The studied section was 7.7 km and the speed limit varies from 100 to 120 km/h.

Road elements along the motorways such as advertisements, signs (varying in content, size and luminosity), active Variable Message Signs (VMS) building entities (toll buildings, railway stations), were examined as distraction causes. The total number of the selected road elements was 136, of which 69 were at the first motorway, 40 at the second motorway and 27 at the third motorway. The general categorization and the percentages are shown in the following chart (Figure 1).

![Figure 1. Categorization of the 136 studied points](image-url)
2.2 Equipment

The equipment used in the survey was carefully chosen in order to achieve the optimal quality, completeness and integrity of results. The chosen equipment Facelab L2100 (Seeing machines) which belongs in the category of eye trackers, was installed in a passenger car and it is consisted of a monitoring and recording system which detects and records every single movement of the driver’s gaze and the driver’s head (the produced video of the external environment shows an indicator on each point the driver gaze focuses for the total duration of his/her gaze). It is composed of two cameras inside the vehicle and an external camera for road environment recording. The necessary settings that the system requires were made for each participant individually in order to create a head model of each driver, which identifies the pupils of the eye and catches every single movement of them. All measurements took place during the day, under normal traffic conditions as well as normal weather and lighting conditions.

A compatible with FaceLab L2100 software (Captiv) was also used in order to analyse videos recorded by the Facelab machine. Via this software, the analysis focuses in specific points of every route, and calculates the total time that a stimulus (billboard, sign etc) captured driver’s gaze. At this point it should be noted that we consider as distraction the continuous or intermittent but repeated capture of the gaze from a theme for 1 second (Rockwell, 1998; Zwalen et al., 1988; Wickman et al., 1998) and for 0.7 seconds by which Beijer et al. (2007). Despite the fact that the indicator on the video scenes clearly shows the direction of the gaze - which means that normal eye panning could be easily be distinguished from gazing at specific road elements - specially trained analysts were participated also in order to properly analyse the scenes.

2.3 Participants

The participants who drove the equipped car were seventy seven volunteers (62% males and 38% females). The vast majority of them possesses a driving license and drives systematically for more than ten years. The selected drivers belong to three age groups, 26-35, 36-45, 46-55 (Figure 2) which contribute more than other ages in road accidents caused by driver distraction (Greek Traffic Police, 2015).

![Figure 2. Participants’ age distribution](image)

Each one of them, in order to become familiar with the vehicle, drove the selected route 2 times before the one that we used for the analysis. The only suggestion to the drivers was to drive and behave as they do with their personal cars. Driving was executed under the supervision of a researcher, who was always seated in the passenger seat checking the proper function of the system.

3 RESULTS

The average distraction time caused by all elements is 1.55sec in Site 1, 1.34sec in Site 2 and 1.48sec in Site 3. Distraction of attention caused by billboards is 1.13sec in Site 1 1.26sec in Site 2 and 1.40sec in Site 3 respectively (Figure 3).
Distraction from advertising exceeds the safe limit of 0.7 or 1 sec by 76% and 57% respectively in Site 1, 96% and 64% in Site 2. In Site 3 all measurements are over 1 second. Other road elements have almost the same distribution and impact on drivers’ distraction compared to distraction from advertising. Site 1 has again the smallest percentage of distraction that exceeds 1 sec (Table 1).

Table 1. Time percentage of the average distraction that exceeds 0.7 and 1 sec.

<table>
<thead>
<tr>
<th>Distraction time</th>
<th>Elements</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 1 sec</td>
<td>All</td>
<td>48%</td>
<td>73%</td>
<td>89%</td>
</tr>
<tr>
<td></td>
<td>Advertising</td>
<td>57%</td>
<td>64%</td>
<td>100%</td>
</tr>
<tr>
<td>&gt; 0.7 sec</td>
<td>All</td>
<td>78%</td>
<td>98%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Advertising</td>
<td>76%</td>
<td>96%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Regarding the driver’s performance, the percentage of drivers whose average time distraction is greater than 1 second is 44% at Site 1 while the 83% exceeds 0.7 sec. In Site 2, 72% and 100% of the drivers are distracted for more than 1 and 0.7 sec respectively on average. The same percentages for Site 3 are 75 and 100% (Table 2).

Table 2. Percentage of drivers with average distraction time over 0.7 and 1 sec.

<table>
<thead>
<tr>
<th>Time</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 1 sec</td>
<td>44%</td>
<td>72%</td>
<td>75%</td>
</tr>
<tr>
<td>&gt; 0.7 sec</td>
<td>83%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

The average distraction time for each category of road element is presented at Table 3. There are certain elements that are not met at every motorway such as VMS that are not placed at the third road so the results are not comparable among the different sites for all categories. As the results show, advertising together with buildings are the leading causes of distraction.

Table 3. Average time of distraction by element type

<table>
<thead>
<tr>
<th>Element Type</th>
<th>Number of elements</th>
<th>Average distraction time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VMS</td>
<td>20</td>
<td>0.93</td>
</tr>
<tr>
<td>Buildings (toll booths, railway stations etc)</td>
<td>23</td>
<td>2.74</td>
</tr>
</tbody>
</table>
As Figure 4 shows, there are buildings that attract driver’s glance for significantly longer time intervals, than other elements. Of the total “building” cases, 88% exceed 0.7sec and 62% exceed 1sec of distraction.

Road elements such as traffic and information signs, noise barriers, telecommunication antennas and road equipment have also an impact on driver’s distraction. In many cases distraction time reaches 1.5 sec. Figure 5 shows that the 90% of the cases is over 0.7sec and 40% exceeds 1sec of distraction.
Table 4 shows that advertisements have a higher distraction time in age of 26-35, as well as the elements of “other” road equipment. On the other hand drivers over 46 years old are more careful to messages of VMSs and focus on driving task since they have less distraction from advertisements and other road equipment.

Table 4. Average time of distraction by driver’s age

<table>
<thead>
<tr>
<th>Element Type</th>
<th>Group age 1</th>
<th>Group Age2</th>
<th>Group Age3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advertisement</td>
<td>1.17</td>
<td>1.10</td>
<td>1.09</td>
</tr>
<tr>
<td>VMS</td>
<td>0.89</td>
<td>0.99</td>
<td>1.14</td>
</tr>
<tr>
<td>other</td>
<td>1.27</td>
<td>1.21</td>
<td>1.13</td>
</tr>
</tbody>
</table>

The examination of driver’s experience shows that drivers with experience less than 10 years have an average distraction time of 0.9sec, drivers with experience between 10-20 years have an average distraction of 1.39sec and drivers with experience over 20 years have an average distraction time of 1.2sec (Table 5).

Table 5. Average time of distraction by driver’s experience

<table>
<thead>
<tr>
<th>Experience group</th>
<th>&lt;10 years</th>
<th>10-20 years</th>
<th>&gt;20 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average distraction time</td>
<td>0.9</td>
<td>1.39</td>
<td>1.2</td>
</tr>
</tbody>
</table>

To sum up, the results show that distraction in general is higher at the first site (Site 1), but distraction from advertising occurs mostly at the other two sites (Sites 2 and 3). The higher average distraction in Site 1 can be explained based on the fact it has a lot more elements such as building facilities, suburban railway stations, toll buildings and Variable Message Signs, compared to Site 1 and 2. Also, the majority of advertisement related points exceeds the safe distraction time limit. The same thing occurs for all other road elements under study. Additionally, there are certain elements that exceed even higher time intervals such as a time of 3sec (Figure 4). According to results based on the average time of distraction by element type, we conclude that the highest average time of distraction in Site 1 is not due to advertisements but due to distraction from other sources which have times, in some cases, close to 3 seconds. The type of distraction caused by the “building” category is frequent in Site 1, mainly in the urban area of the motorway and is related to other structures which are part of the road environment such as toll booths and railway stations (the suburban railway of Athens -constructed in the central reservation of the Attica Tollway). Regarding driver’s characteristics, we conclude that younger drivers seem to be more distracted due to advertisement and “other” road elements. Furthermore, experienced drivers are more likely to be distracted in comparison to the experienced drivers.

4 DISCUSSION AND CONCLUSIONS

The main objective of this paper is the investigation of the existence of driver distraction due to out of the vehicle factors, especially due to advertisement signs in motorways. This goal is met and the results reveal the presence of a dangerous interaction between driver’s attention and the road elements which diminishes road safety and affects driver performance in a way that has to be further examined in a future research.

A naturalistic method was selected for the collection of numerous observations regarding the distraction of driver’s attention in motorways. We used Facelab L2100 eye tracker which measures the time that the driver looks at, for selected road elements. The measurements took place in 3 motorways in Greece.

416
and 136 road elements were examined and 77 drivers participated. The results were analyzed via Captive software.

This research concluded that the average time of distraction varies from 1.34 to 1.55 sec. Advertisements are among the most eye-catching elements of the road. The time of distraction from billboards varied between 1.13 and 1.40 sec. Other elements which distract driver’s attention but are necessary for the driving task such as VMSs, need to be re-examined taking into consideration the message, the position and the traffic conditions close to them. Also, building entities and especially constructions that are part of the road environment (such railway stations in the central reservation) reach the maximum values of all measurements.

Distraction time is critical to be under a specific value with respect to road type, speed, driver behavior and of course road characteristics. Some studies consider as critical time the value of 2 seconds or more and other the value of 0.7 or 1 second. As we resulted by this study the average distraction time is not over than 2 sec. Thus an examination of other factors like the number of entities in each road or the total time that a driver is distracted from the driving task must be conducted.

Also, it is critical to specify the relationship between distraction and accident risk for each road under study. For example Attica Tollway has a little higher average distraction time compared with the other motorways but in the same time is by far the safest motorway in Greece and one of the safest in the word (IRF Safety Award, 2005) with an accidents rate of 0.5 fatal accidents per 100 mil vehicle-kilometres.

In that direction, ongoing analysis will provide more detailed results about user’s characteristics, speed, number of lanes, distance from the road axe and other road and traffic characteristics. Also, a future study needs to focus on the advertising characteristics emphasizing in the content in order to investigate the specific parameters that increase the distraction of the driver. The results of this type of research are useful as a tool to prevent the forthcoming pressure for more and more road elements on the roads that are not related to the driving task as well as to encourage the adaptation of more precise regulations with respect to the road infrastructure design, the placement of roadside elements and the traffic management measures.

ACKNOWLEDGEMENTS
The writers of the present paper acknowledge the contribution of the company Attikes Diadromes S.A. for buying the FaceLab equipment for the purposes of this research. They, also, acknowledge the valuable contribution of all the participants who voluntarily devoted their time and energy to our research.

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AUTOMATED ROAD SAFETY ANALYSIS USING COMPUTER VISION TECHNIQUES

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Road Safety, Automated Traffic Safety Analysis, Traffic Conflicts, Conflict Indicators, Proactive Safety

Traffic safety analysis has often been undertaken using historical collision data. However, there are well-recognized availability and quality problems associated with collision data. In addition, the use of collision records for safety analysis is reactive: a significant number of collisions has to be recorded before action is taken. Therefore, the observation of traffic conflicts has been advocated as a complementary approach to analyze traffic safety. However, incomplete conceptualization, and the cost of training observers and collecting conflict data have been factors inhibiting extensive application of the technique. Therefore, the successful automation of extracting conflicts from video sensors data using computer vision techniques can have practical benefits for traffic safety analysis. This paper describes a comprehensive system for automated road safety analysis using video sensors. The system automatically detects traffic conflicts in video data and calculates several conflict indicators. The paper describes two applications of the automated safety analysis using real-world case studies. The first application deals with a study to diagnose pedestrian safety issues in downtown New York City. The second application deals with evaluating vehicle-bicycle interactions in the City of Vancouver.
AUTOMATED ROAD SAFETY ANALYSIS USING
COMPUTER VISION TECHNIQUES

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1 INTRODUCTION

The occurrence of road collisions is considered a global epidemic causing 1.3 million fatalities worldwide every year (Mathers and Loncar, 2005) leading to astounding economic and societal costs. Therefore, many road authorities around the globe are investing in improving road safety. Since road safety improvement programs are generally dependent on the availability of collision records, the success of these programs is governed by the quality and availability of this data (Sayed and Zein, 1999). In addition, given that the use of historical collision data is a reactive approach, as safety analysts must wait until significant number of collisions occurs before an improvement can be achieved. Several problems are associated with this approach (Sayed and Zein, 1999; Saunier and Sayed, 2007) which include: difficulty of attribution (e.g. the difficulty to identify the collision contributing factors); poor collision data quality and quantity; and an ethical dilemma as collisions, that are required to be prevented, have to occur and be recorded over an adequately long period, typically 3 years, in order to draw informative information and to conduct sound safety diagnosis.

Because of the previous limitations, there is a growing interest in advancing road safety improvement programs that depend on other surrogate safety measures instead of collision data. The observation of road user interactions (traffic conflicts) has been advocated as an alternative approach to analyze traffic safety that doesn't involve collision statistics alone (Amundsen and Hyden, 1977, Sayed et al., 1994; Archer, 2004). This technique (TCT) involves recording and evaluating the frequency and severity of near misses at a location, which enables the safety professionals to immediately observe unsafe driving maneuvers at road locations without waiting for the collisions to occur. The technique was shown to be useful in conducting various safety analysis applications (Autey et al., 2012; Zaki et al., 2013; Sayed et al., 2013). However, the TCT is usually criticized for the high cost of training manual observers and collecting the conflict data. As a result, the automation of the process of extracting conflicts from video data by means of computer vision techniques can have considerable benefits for traffic safety studies and understanding road users’ collision mechanism. Recent advances in the use of video-based computer vision techniques for the automated analysis of traffic conflicts data are showing considerable benefits for conducting traffic safety studies. Vision-based systems for traffic monitoring and analysis can significantly reduce the workload of human observers and help improve our understanding of traffic behaviour. Video sensors for traffic monitoring have a number of advantages, such as the ease of installation and the possibility of securing rich traffic description. Process automation can enable the traffic conflict analysis in an accurate, objective, and cost-efficient way, which addresses main limitations in manual techniques that rely on human observers (Ismail et al., 2011).

The goal of this paper is to describe a comprehensive system for automated road safety analysis using video sensors. The system automatically detects traffic conflicts in video data and calculates several conflict indicators. The paper describes two applications of the automated safety analysis using real-world case studies. The first application deals with a study to diagnose pedestrian safety issues in downtown New York City. The second application deals with evaluating vehicle-bicycle interactions in the City of Vancouver.

2 THE VIDEO ANALYSIS APPROACH

The safety analysis is performed through a video analysis procedure using a computer vision system, developed at the University of British Columbia. The video analysis system automatically detects, classifies, and tracks road users and interprets their movement. For road safety applications, the proposed approach relies on the building of two databases: a trajectory database, where the results of the video processing module are stored, and an interaction database, where all interactions between road users are considered, and
for which various conflict indicators can be automatically computed. Identifying road-user behavior, traffic violations, traffic conflicts and measuring other traffic parameters can be achieved through mining these databases (Saunier et al., 2010).

**Road-Users Detection:** The automated video analysis relies on computer algorithms to differentiate between features of road users and features that are part of the environment (Saunier and Sayed, 2006). Features are identified and tracked using the Kanade-Lucas-Tomasi Feature Tracker algorithm (Saunier and Sayed, 2006). Feature-based tracking identifies distinguishable features (e.g. window corners, bumper edges) on the moving object. (See Figure 1.a). Since a moving object can have multiple features, the next step is to group the features, using spatial and temporal cues. (See Figure 1.b). The subsequent step is the road-users classification (Zaki and Sayed, 2013). The objects trajectories hold features that reveal the structure of the traffic movements and provide important clues to the characteristics of the road-users (e.g. pedestrian ambulation, cyclist pedaling, maximum speed). Such information provides a basis for a classification decision procedure (See Figure 1.c). The road-users tracking and classification accuracy were presented in (Ismail et al., 2010) where tracking error was found to be satisfactory low.

**Camera Calibration:** The positional analysis of road users requires accurate estimation of the camera parameters. Camera calibration is the process of determining the homography matrix of a camera angle, and is necessary for tracking road users in the camera image and relating these tracks to positions in the real-world. Each calibration process begins with the user annotating features in the camera image and in an aerial, orthographic image of the intersection. Details of the adopted mixed-feature camera calibration approach are presented in (Ismail et al., 2013).

**Safety Analysis:** The adapted safety analysis provides an operational interpretation to automatically capture the traffic conflicts between road-users. The implementation relies on matching the trajectories to prototypical trajectories from the full set of previously learned motion patterns (Saunier and Sayed, 2006) (See Figure 1.d). The prototypes provide a set of predicted future positions with associated probabilities of occurrence. Conflicts between road-users can then be determined by evaluating if any of these future positions coincide spatially and temporally with other road-users (See Figure 1.e). Details of the procedure are explained in (Saunier and Sayed, 2006).

![Features Tracking](image1)

![Features Grouping](image2)
In the case studies considered in this paper, the conflict indicator used as a measure of proximity between road users is the Time to Collision (TTC). TTC is continually calculated between conflicting road-users. The minimum TTC, is then extracted from this set to indicate the maximum severity of this interaction. In this paper, only traffic events with associated minimum TTC of less than 3 seconds are considered for the safety evaluation. This value was selected based on the work in (Sayed and Zein, 1999). Other conflict indicators are also used to capture different proximity aspects. Post-Encroachment Time (PET) (Archer, 2004) is defined as the time difference between the moment an offending road user leaves an area of potential collision and the moment of arrival of a conflicted road user possessing the right of way. PET is considered as a suitable safety measure between turning vehicles and pedestrians (Ismail et al., 2010).

3 CASE STUDIES

3.1 Automated Pedestrian Safety Diagnosis at a Signalized Intersection in New York City

This case study demonstrates the potential benefits of using computer vision techniques to collect pedestrian data in a densely populated urban city and use it to study pedestrian behavior and to assess pedestrian safety. The main objective of this case study is to diagnose pedestrian safety by assessing pedestrian safety issues at the studied intersection and identify factors contributing to them. Traditionally, road safety analysis is largely dependent on statistical analysis of aggregated collision data. This approach has numerous shortcomings as summarized in (Saunier and Sayed, 2007). In order to overcome these shortcomings, surrogate measures of safety such as the traffic conflict technique have been advocated as an alternative approach to analyze road safety (Sayed and Zein, 1999; Chin and Quek, 1997). In this case study, the traffic conflict technique (TCT) was applied to assess pedestrian safety at the study location. The analysis was conducted using an automated road safety analysis system described earlier. The current system can detect, track, and classify road users and measure severity of conflicts in complex urban intersections. As well, an analysis of pedestrian temporal violations (using the time not designated for pedestrians to cross the street) and spatial violations (using areas not designated for pedestrians to cross the street) is conducted.

Video data were collected from the busy signalized intersection of Park Avenue South and East 28th Street in New York City. Park Avenue South is a two-way north-south roadway with two moving lanes and a parking lane in each direction (total roadway width = 21.6 m). East 28th Street carries one-way eastbound traffic (total roadway width ranges from 10.4 m to 11.2 m). The intersection is controlled by a pre-timed signal (cycle length = 90 seconds). Right turn on red is not allowed and permissive left-turn phases are provided on all applicable approaches (28th Street eastbound and Park Avenue southbound). The 28th Street subway station is located at the intersection, contributing to high pedestrian activity, particularly during peak hours, as pedestrians enter and exit the station. Data used in this study were collected on May 7th, 2014 during morning peak hours between 7:35 AM and 9:32 AM. The study focused on pedestrian-vehicle conflicts on the east crosswalk (crosswalk 1) and the north crosswalk (crosswalk 2). For the east crosswalk,
pedestrian-vehicle conflicts are expected to occur between pedestrians and northbound right-turning vehicles and southbound left-turning vehicles. Pedestrian-vehicle conflicts on the north crosswalk are expected to occur between pedestrians and eastbound left-turning vehicles.

3.1.1 Summary of Findings

The heat map of the automatically identified pedestrians-vehicles conflicts is shown in Figure 2. The map represents the intensity of the identified conflicts at the intersection (conflicts/m²). The number of identified conflicts by severity is shown in Table 1. On average, 72 pedestrian-vehicle conflicts occur per hour, which is very high compared to other published pedestrian safety studies. For example, a recent study (Zaki et al., 2013) that analyzed pedestrian-vehicle conflicts on one of the busiest intersections in downtown Vancouver, British Columbia reported 204 conflicts during 8 hours on two perpendicular cross walks of the intersection (average of 25.75 conflicts per hour). The hourly average number of conflicts identified in this study is almost triple those observed in Vancouver study despite the fact that only part of the northbound crosswalk is considered for analysis. Additionally, one of the intersecting streets (East 28th Street) is a one-way street while in the Vancouver study both streets were two-way streets. Figure 3 shows sample of conflict events detected in the scene.

Figure 2. Pedestrians-vehicles conflicts heat map on both camera world images (conflicts/m²)

<table>
<thead>
<tr>
<th>TTC Range (Seconds)</th>
<th>Number of Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 &lt; TTC ≤ 1</td>
<td>70</td>
</tr>
<tr>
<td>1 &lt; TTC ≤ 2</td>
<td>46</td>
</tr>
<tr>
<td>2 &lt; TTC ≤ 3</td>
<td>28</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>144</strong></td>
</tr>
</tbody>
</table>

This high rate of conflicts is likely related to higher pedestrian volume and pedestrian violation rates. A high percentage of pedestrian conflicts were due to pedestrian violations. As can be observed in Figure 3, the main reason behind the conflict events is pedestrian violation, especially temporal violation. Many pedestrians start crossing the street during the Don't Walk phase and therefore conflict with vehicles that try to cross the intersection during their amber phase. Although the signal only allows pedestrians on the parallel crosswalks (i.e. north crosswalk and south crosswalk or east crosswalk and west crosswalk) to move at the same time, pedestrians were often observed at two adjacent crosswalks at the same time (see the four snapshots in Figure 3). This demonstrates that many pedestrians were not following the signal indicators and therefore in violation. Table 2 summarizes the hourly observed pedestrian violations in both crosswalks. On average, almost one-third of pedestrians were involved in a violation event (17.9% were spatial violations and 15.3% were temporal violations). Observed hourly spatial violation was 7 times higher than observed hourly violations in the Vancouver study (Zaki et al., 2013). Figure 4 shows sample of violation events observed at the intersection.
Table 2. Pedestrian Violations

<table>
<thead>
<tr>
<th></th>
<th>Count (Pedestrian/hour)</th>
<th>Spatial Violation (per hour)</th>
<th>Temporal Violation (per hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crosswalk 1</td>
<td>684</td>
<td>92 [13.5 %]</td>
<td>152 [22.2 %]</td>
</tr>
<tr>
<td>Crosswalk 2</td>
<td>1304</td>
<td>264 [20.2 %]</td>
<td>152 [11.7 %]</td>
</tr>
<tr>
<td>Total</td>
<td>1988</td>
<td>356 [17.9 %]</td>
<td>304 [15.3 %]</td>
</tr>
</tbody>
</table>

Figure 3. Sample snapshots of pedestrian-vehicles conflicts

Figure 4. Sample snapshots of pedestrian violations
3.2 Diagnosing Safety Issues of Vehicles-Bicycles Interactions Using Automated Computer Vision Analysis

Video data was collected at the intersection of Burrard Street and Pacific Street in downtown Vancouver. The intersection represents the entrance of the southern approach of a major Bridge in the city; Burrard Street bridge. The intersection analyzed in this case study was selected because of perceived high rate of conflicts between vehicles and cyclists. Figure 5 illustrates the conflicts regions for typical trajectories of the road-users. Right-turning vehicles in the ramp should yield for bicycles travelling southbound to the Burrard Street Bridge. However, the current configuration limits the available sight distance leading to severe conflicts. For the northbound approach of the intersection, a large portion of northbound cyclists will go off ramp onto another bike lane. Yet, some cyclists will have to cut through the vehicles right-turn lane in order to take the through lane towards Burrard Street.

Figure 5. Possible Conflicts Regions for Vehicles-Bicycles Interactions

3.2.1 Summary of Findings

Traffic conflicts between vehicles and bicycles at both approaches of the intersection are automatically identified. Conflict analysis includes identifying conflict frequency, severity and location (conflict points). Distribution of the vehicle-bicycle conflicts (with a minimum TTC smaller than 3 seconds) by heat mapping is shown in Figure 6. Those conflicts considered of high severity were carefully analyzed leading to recommended safety countermeasures as will describe later.

Figure 6: Conflicts Frequency Heatmaps (Conflicts/m2) for the Burrard & Pacific Intersection

Tables 3 shows a breakdown of the number of cyclist-vehicle conflicts by type and severity. For southbound traffic, the majority of the conflicts were observed between vehicles non-conforming to the yielding signage
and the cyclists arriving from the Burrard Street bike lane and crossing towards the Burrard Bridge bike lane. This is attributed likely to the limited sight angle for the drivers who in most cases are not aware to the arrival of cyclists. Out of the 229 cyclists, 72 were in conflicts with vehicles as shown in Table 3, which is 31.44 percent of the cyclists. On the northbound approach, according to Table 3, 35 cyclists were in conflicts, representing 23 percent of cyclists traveling northbound. It is worth mentioning that out of 149 cyclists; only 39 chose to travel on the bike lane crossing the vehicles heading to Burrard Street, while the remaining majority (110) chose an alternative safer path by going straight on the sidewalk.

The analysis of important events such as conflicts led to the proposal of some recommendations that can act as safety countermeasures. One recommendation is better signage and road markings. Cyclists crossing area should be clearly strip marked to indicate that vehicles should not stop in this area.

<table>
<thead>
<tr>
<th>Conflicts</th>
<th>Southbound Bikes and Right-turn Vehicles (Camera angle 2)</th>
<th>Northbound Cyclists and Right-turn (Camera angle 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTC range</td>
<td># Events</td>
<td># Events</td>
</tr>
<tr>
<td>0-1 seconds</td>
<td>34</td>
<td>19</td>
</tr>
<tr>
<td>1-2 seconds</td>
<td>23</td>
<td>16</td>
</tr>
<tr>
<td>2-3 seconds</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>72</td>
<td>35</td>
</tr>
</tbody>
</table>

4 DISCUSSION

This paper presented the application of a proactive safety diagnosis procedure where video analysis is employed to automatically identify and analyses serious events such as traffic conflicts and violations. Traffic conflict techniques (TCT) were adopted to diagnose pedestrian safety at an intersection in downtown New York City. On average, 72 pedestrian-vehicle conflicts occurred per hour on the two crosswalks analyzed in the study, almost triple the number of pedestrian-vehicle conflicts identified in one of the busiest intersection in the City of Vancouver. It was observed that the main contributing factor to the high number of pedestrian-vehicle conflicts was pedestrian violations, mainly temporal violations. Pedestrians start crossing during the “Don’t Walk” phase and, therefore, conflict with vehicles that try to cross the intersection during amber phase. During the two hours analyzed, about one-third of pedestrians tracked were involved in a violation event (17.9% spatial violations and 15.3% temporal violations). Observed hourly spatial violations were seven times higher than observed hourly violations in the City of Vancouver study. As pedestrian violations appear to be the major contribution of the safety issues at the intersection, it is recommended to apply countermeasures that can decrease the number of violations. Engineering solutions are useful to provide better signal design to satisfy pedestrian needs and study all factors that motivate pedestrians’ non-compliance to signals. Education, public awareness and enforcement measures can also be effective. The procedure was also applied to the safety analysis of a newly installed bike lane at the entrance of the southern approach of a major Bridge in Vancouver, British Columbia. The results showed a high exposure of bicycles to traffic conflicts. The study also presented potential countermeasures to address the safety issues at the location. Further development is desired along the analysis procedure. That includes further enhancement and adoption of more accurate road-users tracking and classification. Other developments include the calculation of other severity indicators (e.g., gap-time) to provide more cues for the underlying level of safety of the facility and to set a connection to other safety standard indicators like collision frequency (El-Basyouny and Sayed, 2013; Sacchi et al., 2013). Future work will also include evaluation of the practicality of the proposed approach can only be achieved through the thorough applications to additional case studies sites.

5 REFERENCES


NEW LIFE TIME PERFORMANCE OF CONCRETE VEHICLE RESTRAINT SYSTEMS

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ABSTRACT

In year 2014 a national authority of an EU-member state officially withdrawn the approval of in-situ concrete vehicle restraint system from its market.
What was the reason for such a tough decision?
What is and will be the answer from the industry?
What will that mean for the future in-situ concrete vehicle restraint systems?

In the end of the year 2013 the current condition of existing in-situ concrete vehicle restraint systems within a specific region was scientifically reviewed. It was the goal to get a true and real picture of the actual safety performance of that specific barrier type after being exposed to real life conditions for many years. The detailed investigation by an independent laboratory brought up, that the safety performance of that specific barrier type was significantly reduced after seven years and totally lost after fourteen years.

There are many factors that influence and limit the performance lifetime of a product. In case of in-situ concrete vehicle restraint system in the central reserve it is mainly the environment and climatic conditions. The most disadvantageous climate for in-situ concrete vehicle restraint systems is high peak temperatures in summer, strong and quick changes of temperatures, many changes from frost to thaw and the appearance of the barriers enemy number one – chloride.

In a wet environment Chloride increases steel corrosion significantly. Depending on specific boundary conditions pitting corrosion can result in significant and fast damage to steel and reinforcement. Normally Chloride is no problem for reinforced concrete products if the right concrete quality is chosen and the coverage of the reinforcement is sufficient. However in-situ concrete vehicle restraint system do have a weak point in that case as the barrier cracks naturally due to the hardening and curing process and temperature elongation. A reliable prevention of these cracks is not possible. In some countries the cuts must be sealed to prevent penetration of water and chloride and their direct contact with the reinforcement. This was the technical solution so far, but today it is proven that even sealing of the obligatory cuts of in-situ concrete vehicle restraint system cannot create a durable protection to guarantee a sufficient performance lifetime.

Under the pressure of authorities some companies have developed and crash tested new reinforcement types for in-situ concrete vehicle restraint system that withstand typical corrosion mechanism and chloride for 25 and even up to 50 years. This upgrade brings back that important barrier construction method to the highways central reserve. Now the reinforcement type can be chosen according to the required performance lifetime and the applicable climatic conditions.

The presentation will give a summary of the evaluation of the performance lifetime of existing in-situ concrete vehicle restraint system. The corrosion mechanism caused by chloride in context with the traditional construction methods of in-situ concrete vehicle restraint system will be explained. General technical solutions will be outlined. The technology of an in-situ concrete vehicle restraint system construction method fulfilling the new product lifetime criteria for the road network will be presented.

KEY WORDS
BARRIER, CONCRETE, IN-SITU, ROAD SAFETY, VEHICLE RESTRAINT SYSTEM
1. THE DUTCH STEP-PROFILE IS STANDARD IN MOST EUROPEAN COUNTRIES – BUT ARE THERE ALTERNATIVES?

In 1995 the Dutch step barrier achieved performance class H2/W1/ASI B. Since then many engineers in Europe have tried to retest and improve the Dutch in-situ concrete barrier concept. Surprisingly no one was able to reproduce the results of these 1995 crash tests up to now. In fact more than 20 TB11 passenger car tests have been carried out, but all resulted in ASI C, which is not accepted in most European countries. Therefore the original 1995 Dutch barrier is still used in Europe and the test result ASI B from 1995 is questioned by many experts today. In November 2013 this specific barrier type has even lost its approval in Germany after detailed technical and legal examination.

With the task of developing a new in-situ concrete barrier which clearly provides ASI B according to the actual standards and test methods an engineering team in a specific composition was sent into the race. One of the biggest in-situ builders in Europe and a specialist in the field of precast concrete barriers shared their knowledge to be able to design a new generation of in-situ barriers basing on theoretical and practical expertise.

2. STATE OF TECHNIC IN-SITU BARRIERS

After an extensive development and crash-test program a new generation of in-situ concrete safety barriers was created recently to set new standards in this field. Being the core for further developments this new technology got rid of some well-known disadvantages regarding production, repair and maintenance, non-compliance with standards and compatibility with other types of safety barriers. The new “EP 80B” series is up to define the state of the art in its field of technology.

3. ENHANCING THE PRODUCTION QUALITY

With in-situ barriers the quality of production is generally defined by the quality of the concrete mixture plus treatment, the operation of the slip-form paver, the accuracy of the reinforcement and the consideration of influencing boundary conditions like soil, climate and application method. The new technology reflects on these issues providing more security not only regarding the barrier lifetime but also the performance lifetime. Experienced in-situ barrier producers and manufacturers of slipform paving machines gave their inputs to enhance the guidance of the steel strands outside and within the mould. For quality control a procedure was found, that provides training and certification of staff and operators, detailed description of limits for production conditions like temperature and climate as well as checklists for continuous optical quality control.

FIGURE 1 - EN 1317 TB51 impact tests on the “EP 80B” series, H2/W2/ASI B without deflection
4. PRODUCT LIFETIME – PERFORMANCE LIFETIME

Normally steel bars or coils are used as longitudinal reinforcement. As they need to be welded to create a continuous tension bar this reinforcement normally cannot be galvanized. One would argue that the concrete coverage is by far enough to create passive corrosion protection, but the problem rests within the production process. An in-situ barrier cracks within the curing process and due to stress caused by variations of temperature. Furthermore the production process is very sensitive as high pressure due to compaction inside the mold and high paving speeds might cause typical head cracks which often are not visible first. Cutting the barrier in a defined depth and distance is obligatory today to get control of the typical cracking. However where there are cracks there is penetration of water and salt and there is corrosion of the reinforcement, no matter how much concrete coverage there is. This fact is reducing the possible product lifetime seriously and the performance lifetime dramatically. So for the designers of the new generation in-situ barrier it was clear that a proper and serious product lifetime can only be achieved by using galvanized steel. This resulted in the need for a new method of connecting the reinforcement to a continuous bar. A solution was found in the technology of pre-stressed precast concrete elements. By using modified coupling units for steel strands a highly effective method was developed to connect non pre-stressed galvanized strands for the application in in-situ concrete safety barriers. These couplings have proven their capability in practice even under the extreme conditions inside a slip form mold. Furthermore the couplings have been installed in crash-tested barriers at the impact point. The new coupling method worked extremely well. There was even no indication of any slipping of the steel strands in the coupling.

5. COMPLIANCE WITH ACTUAL STANDARDS

Because in-situ concrete barriers are naturally very massive and rigid, the impact severity and passenger protection in light vehicles are in a critical range and an intensively discussed issue European wide. This crucial topic is solved now as the new in-situ barrier has proven impact severity class ASI B already in several crash tests. This means that the basis for further product developments is found. As the core product provides the necessary features to fulfill todays and future requirements the product range can be extended with crash tested transitions, different modifications and optimizations as well as alternative application methods. Also higher containment levels will be possible now at classification ASI B.
6. THE CONSTRUCTION JOINT – CRASH TESTED FOR UTMOST SAFETY

Theoretically a slipform paver can produce a continuous concrete barrier of infinite length. However in reality the machine produces in best case a length it can build within a dayshift which is usually 200 to 400m. At the next shift the machine starts again on the hardened end section of the previous day. This results in a construction joint where fresh concrete meets slightly hardened concrete. The reinforcement is usually continuous right through the joint, but the concrete structure is significantly disturbed so the construction joint must be considered as significant weak point. After impact tests on typical construction joints the influence on the barriers impact resistance was obvious. Therefore the new developed in-situ barrier should also include a solution for construction joints providing full breakthrough resistance at the specific containment level. After strengthening the joint with steel dowels and additional reinforcement a TB51 crash test was carried out to prove the effectiveness.

The new construction method for construction joints can also be applied on repair works. Although in-situ barriers show a very robust impact behavior they also can be damaged significantly when impact energy is exceeding the barriers capacity. In that case professional repair is necessary which should recreate the original safety performance. Until now there was no defined repair method available that has proven its effectiveness in an EN1317 crash test. By using a new innovative coupling method for the continuous reinforcement it is now possible to seamlessly exchange parts of the reinforcement without welding on site and therefore without compromise in corrosion protection. As all parts of the repair-system are galvanized the lifetime of the barrier must not be reduced. Now even a repaired section of the new in-situ barrier can be considered as fully EN 1317 crash-tested part of the system.
7. APPLICATION METHODS

When crash-testing a barrier the developer must very carefully consider the application method. Normally in practice the barrier must be installed exactly as it was crash tested. If the in-situ barrier was tested embedded in the asphalt at a depth of 5cm it must be installed that way. If it was tested embedded in a continuous asphalt layer it normally should not be installed on verge application. There the asphalt abutment is limited in its width and cannot provide the needed support for the barrier. The development approach for the new barrier was rather clear. It must be crash-tested in the worst case scenario considering different application methods. However it is clear that all installation methods cannot be covered by one single test. Therefore several setups were crash-tested with the same barrier type. Thus allowing a wide range of application - exactly what is needed for modern road design.

![Figure 5 - EN 1317 TB51 impact test on the surface mounted EP 80B without any deflection](image)

8. COMPATIBILITY TO PRECAST CONCRETE BARRIERS AND OTHER SYSTEMS

Modern road design demands a wide range of special barrier types for numerous applications. For concrete barriers the most important application is the central reserve. But even within the central reserve there are several barrier types needed for maintenance crossing points and emergency crossing points plus crash tested transitions, special bridge systems for the median as well as special barriers for the protection of bridge piers, gantry piers and light posts. On the verge mostly steel guardrails are used because the needed containment level is lower and maintenance is of secondary importance. However also on the verge there is the need to protect traffic against rigid obstacles. Also in these cases concrete barriers are often the preferred choice. On bridges precast concrete barriers are widely used when highest containment levels are required. So it is a clear necessity that the new in situ barrier must be fully compatible to different barrier types and also steel guardrails. Only then the barrier can be considered as core product for the central reserve respectively high-ranking roads.

In Belgium there was the need for rehabilitation and upgrade of the A15 E42, St-Georges – Andenne. In the original project design the standard Dutch in-situ concrete step barrier was foreseen to be installed in two row application in the central reserve. Then the decision was made to put the new in-situ barrier EP 80B-E in place. Major criteria for that was the fully proven ASI B performance according to the actual version of EN1317 and the compatibility to precast concrete barriers for maintenance crossing points. The total project length was 20 km requiring 40 km of barrier. The first phase of the project was carried out in June 2013. 7,800 meters were produced by two slipform pavers within 10 working days. The cutting of the barrier was done directly after the paving by a fully automated cutting machine to realize the needed accuracy. At the transitions to precast concrete safety barriers special steel covers were used so that the slipform paver could directly start at that connection point. There was no need for a complex and time consuming handmade section with hand shutters. Galvanized steel strands were used together with the new coupling devices. Because the whole barrier concept was intensively tested before everything went very well right from the beginning and first meter of production, even though the time pressure was quite hard. The new in-situ barrier has proven its applicability in practice for the full satisfaction of the contractors, clients and authorities.

FIGURE 7 - 7800m of the new “EP 80B-E” have been produced in 10 working days with two slipform pavers to meet the challenging project program of the A15 in Belgium.
10. CONCLUSIONS

Today’s technology in the field of in-situ concrete safety barriers has not really changed in the last two centuries. Still the original design from the early 90’s is widely used – more or less in different modifications. After an extensive development and crash-test program a new generation of in-situ concrete safety barriers was created recently to set new standards in this field. Being the core for further developments this new technology got rid of some well-known disadvantages regarding production, repair and maintenance, non-compliance with standards and compatibility with other types of safety barriers. The new generation of in-situ barriers offers performance class H2/W2/ASI B/VII in several applications and installation methods as well as full compatibility to a whole range of modern precast concrete safety barriers. The crash tests have been carried out considering the worst case scenarios for utmost safety in practice. Construction joints have been crash-tested to also provide a reliable and safe repair method for in-situ barriers. Now the system has already proven its performance in practice on a 40km project on the A15 in Belgium, where it was considered as the preferred in-situ solution over the standard step-barrier from 1995.

11. CITATIONS AND REFERENCES

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Assessment of barrier transitions – the French example

Clément GOUBEL, Jean BLOCH – Transpolis
Pierre DEROMMELAERE – ASCQUER

Abstract

Work on the part of EN 1317 covering the evaluation of transitions has been delayed due to difficulties to find a consensus between all the EU member states within CEN working groups. One has to consider that transitions are an issue which can be considered in more than one way. For instance, the “safety” aspect can lead to complex test matrices including numerous crash tests which will be almost impossible to realize in consideration with economical aspects. In this context, the suspension of the work on a European Standard leaves each member state free to define its own rules until a European agreement is found, allowing technical issues identified during the discussion of CE marking to be resolved on a national basis. The French proposal is to define three different classes of evaluation depending on the type and complexity of the transition. “Simple” transitions (better called connection of devices inside a range of products having the same containment level and no specific part), could be NF marked without any additional evaluation. “Middle class” transitions, would be evaluated through a Computational Mechanics study with several impact points for both TB11 and containment test simulations. Finally, for the more “complex” transitions, one containment test will be required. The tests results will allow obtaining a correlated model of the transition which will be used to assess the performances for other impact points and TB11 evaluation. The presentation will give some details about the philosophy of the French approach, and, more specifically, will present the definition of the three above mentioned classes of evaluation. The French approach combines real testing and computer simulations in order to obtain a reasonable cost for the evaluation of the transitions between devices without any compromise on safety. Some examples will be shown in order to illustrate this assessment method.

Introduction

The programme of work of the CEN TC226 / WG 1 (the European Committee of Standardization working group on crash barriers, safety fences, guard rails and bridge parapets) mainly consists of deliverables defining the requirements, performance classes, impact test acceptance criteria and test methods for the different categories of road restraint systems. This is the definition of the content of EN 1317 parts 1 to 8. Some parts an EN (European Norms) others are either TS (Technical Specifications) or TR (Technical Report). The current part 4 which is and experimental norm ENV 1317-4 covers the evaluation of performance of terminals and transitions for safety barriers. Removable barrier sections are also covered, however they are considered to be a special type of transition. ENV 1317-4 is, to be replaced by two separate supporting standards: prEN1317-4 relating to transitions and removable barrier sections, and prEN 1317-7 covering terminals. Nevertheless, the work on transitions is still under progress and, for the time being, only a TR (a Technical Report), not an EN (European Norm) is envisaged since work on an EN has been suspended to allow national legislation to be put into place.
Current Practice for the assessment of Transitions.

In the ENV 1317-4 the containment classes, the crash test definitions and acceptance criteria are the same as in EN 1317-2, which is the standard for longitudinal barriers. This means that, to be accepted, each transition must be tested twice: a first test with a passenger car to assess the severity of the impact, and a second crash test with the heavier vehicle in order to check the containment performance of the system.

For each test, the most critical conditions for the direction and the impact point must be chosen. In general, the impact direction goes from the softer barrier (the lower containment level) to the stiffer one (the higher containment level).

The critical impact point is in general located at the 3/4th of the transition length for a car, but for a heavy vehicle, the impact point is in the middle of the transition.

Present situation with respect to ENV 1317-4

ENV 1317-4 was defined in 2001 as an experimental standard, but it was to be transformed as a European standard within 4 years after edition. So, in 2005, the member states had to decide either to transform this ENV into an EN or to redefine completely this part. This second position was decided by member states which started to work on a new definition of standards for transitions and terminals.

The work resulted in the division of ENV 1317-4 into two new projects:
- prEN 1317-4: Road restraint systems - Part 4: Performance classes, impact test acceptance criteria and test methods for transitions of safety barriers
- prEN 1317-7: Road restraint systems - Part 7: Performance classes, impact test acceptance criteria and test methods for terminals of safety barriers

Since that time, in 2005, a lot of work was done to define a new way for the assessment of barrier transitions. The principle was to take into account the large amount of possible transitions and an economically optimized way of evaluating their performances. The discussions were based on a combined use of real crash tests and computer simulations, depending on the type of transitions. Nevertheless, it was not possible until now to reach a consensus in order to be able to define a European standard and so the CE mark of transitions.

The French position for the assessment of barrier transitions

In front of this lack of European standard, the French manufacturers, as well as the road authorities asked for several years to get some way of certifying the transition performances. In fact, they argued the difficulties met on the market when transitions must be installed. They had to face questions of performances, of responsibilities. Nevertheless, as a European member state cannot develop its own standard when a European standard is under development, the situation was blocked until authorization given by the European Commission to the French authorities to use their own provisional certification process.

An Ad-Hoc working group driven by the French notified certification body ASCQUER representing AFNOR and including manufacturer representatives developed a certification process which resulted in a Ministerial Decree dated 28 August, 2014.

Since the publication of this decree transitions must be certified by ASCQUER and be NF marked.
This work done in France was to consider the well-known difficulties as the variety of possible transitions, the relatively reduced market and also the major safety issue. So the principle at the beginning of the work was to adapt the evaluation method to the type of product.

The French commission devoted to this work was to consider optimized assessment methods depending on the type of barriers to be connected.

**3 classes of transitions were defined:**
- Class A: transitions do not require evaluation work
- Class B: transitions which require only numerical studies
- Class C: transitions requiring numerical studies and real crash test

In order to decide which class is applicable to a transition, the following criteria are considered:
- Are the two barriers members of the same family of products?
- Are the two barriers with the same containment level? If yes, what is the difference between dynamic deflections?
- Does the transition need any specific part?

This can be summarized in the following table.

<table>
<thead>
<tr>
<th>Family of product</th>
<th>Restraint level</th>
<th>ΔDd</th>
<th>Specific transition part</th>
<th>Evaluation class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>Same</td>
<td>≤ 50 cm</td>
<td>n.a.</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 50 cm</td>
<td>n.a.</td>
<td>B</td>
</tr>
<tr>
<td>Different</td>
<td>(except L level)</td>
<td>n.a.</td>
<td></td>
<td>B</td>
</tr>
<tr>
<td>Different</td>
<td>Same</td>
<td>≤ 50 cm</td>
<td>No</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 50 cm</td>
<td>Yes</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Different</td>
<td>n.a.</td>
<td>Yes/No</td>
<td>C</td>
</tr>
</tbody>
</table>

**A Class transitions**
When a transition is classified in this category, it means that the 2 barriers to be connected have compatible designs which avoid the use complementary parts. The acceptance of the transition is based only on design compatibility.

**B Class transitions: Numerical studies**
The study is based on the models of the 2 barriers to be connected. No correlation work is due for the impact simulations on each barrier. Only simple failure modes check is to be done for each device.
Crash tests are simulated for both containment test and severity test (TB11) and a parametric study must be done in order to determine the effect of different impact points.

**C Class transitions: Containment crash test and numerical studies**
First of all, the **real crash test** for the containment assessment must be performed at the worse impact point. Then, the barriers and transition are modeled and the real crash test is reproduced by digital simulation. A correlation between the simulation and the real crash test must be performed.

The final step is to simulate both TB11 and the containment crash test. This simulation study must include a parametric study on the impact point location in order to assess the efficiency for user’s protection and safety.

**Conclusion**

At the moment, many different transition between different type of barrier (steel barriers to concrete barriers, steel to steel,..) has been assessed an then NF marked following this procedure. This result in a better and safer way of connecting barriers on the roadsides and we are convinced that this method and the related acquired experience can be either applied in other countries or even serve as a working base for CEN TC226 / WG1 in order to define a European standard for the CE certification of transitions.
Abstract:

John Fitch, yacht and race car driver, World War II pilot and POW, invented several automotive products and roadside safety devices, including the yellow, plastic sand barrel. The yellow sand barrel has saved several thousand lives since its first appearance in the 1960s. The New York Times noted in its obituary (Fitch died in Oct., 2012) that the Fitch Inertial Barrel is believed to have saved “over 17,000 lives” since its inception.

The yellow sand barrel also launched a new category of roadside safety devices commonly known as “crash cushions”. Today, “crash cushions” are available in many different styles, types and costs.

We will examine the different types of crash cushions currently available. We will briefly review their design purposes, the features and benefits thereof, and their limitations. As briefly, we will explain sand barrel crash test requirements in the United States.

Last, and perhaps most important to government entities building new infrastructure, we will examine costs associated with each type of crash cushion. Our discussion will include purchase, installation, maintenance, and replacement costs.

With sound information about design and costs, those entities can begin to make informed safety and purchasing decisions.

Sand Barrel Crash Cushions: An Overview of Design, Types and Cost

I.) Types of Crash Cushions and their Use:

A.) Crash Cushion Description and Applications

AASHTO (Association of American State Highway Transportation Officials) publishes several guide books, including the Roadside Design Guide. Recognized as a preeminent resource document, the guide contains information and practices about roadside safety treatments and devices. In the USA, state Departments of Transportation (DOT) uses the guide to develop standards and policies.

AASHTO Roadside Design Guide (Hereafter, RDG) describes crash cushions, also known as impact attenuators, as protective devices that:

- significantly reduce the severity of impacts with fixed objects
- decelerate a vehicle to a safe stop for head-on impacts
- can redirect a vehicle away from the fixed object
- are ideally suited where fixed objects cannot be removed, relocated, or made to break away
- or where they cannot be adequately shielded by a longitudinal barrier (1)

Crash cushions do not prevent crashes per se; they reduce the severity of crashes, but do not prevent their occurrence.
RDG also describes where crash cushions are commonly deployed. Crash cushions are used at exit ramp gores, where drivers need to be protected from bridge rail ends or bridge piers. Crash cushions are also deployed to protect drivers from the ends of median barriers.

Crash cushions are also used in temporary, construction work zone applications. They are often deployed at the ends of portable concrete barrier that separates drivers from the work site and construction workers.

Because of their relatively low cost, and very successful safety history, crash cushions have been proven to be the ideal device for these applications. (1)

**B) Types of Crash Cushions:**

Crash cushions vary in design, function, cost, and repair and maintenance requirements. The roadside safety industry manufactures several types of crash cushions.

Following is a brief description:

**Sacrificial or Reusable:** Sacrificial crash cushions normally do not survive the first impact. They are single impact devices. Reusable crash cushions can survive the first impact, in part or whole. According to RDG, “These devices generally offer low initial costs and can be cost effective if placed in locations where the designer expects infrequent crashes to occur.” (2)

**Low Maintenance and/or Self Restoring:** These crash cushions survive an impact with little damage. They can be returned to their original installation position. Crash cushions can be one or the other or both low maintenance and self-restoring. “Often these products are installed in high-speed, high-traffic volume ramps or medians to reduce the exposure of maintenance workers to traffic.” (3)

**Redirective or Non-Gating:** Here, the terms are synonymous. A redirective crash cushion, when hit from the side, deflects the vehicle, sending it in the opposite direction. The vehicle does not pass through the attenuator, so it is non-gating. A redirective crash cushion, when hit head on, slows and stops the vehicle by its internal parts collapsing. (4)

**Non-Redirective or Gating:** A non-redirective crash cushion, when hit from the side, will not deflect the vehicle. Rather, the vehicle usually passes completely through the crash cushion; this is known as gating. When hit head on, a non-redirective crash cushion slows and stops the vehicle by transferring the momentum from vehicle to crash cushion. (5)

![Figure 1: SCI Smart Cushion, a redirective, non-gating, low maintenance, compression crash cushion.](image)

**C,) Factors for the Selection of Crash Cushions**

Several factors should be considered in the selection of the appropriate crash cushion for the installation site.

Crash history will of course provide the frequency of vehicle impacts at a given location. Where crash history is not available, the amount of average daily traffic (ADT) the roadway will carry can indicate the amount of impacts a crash cushion might experience. The proximity of the crash cushion installation to the roadway will also affect impact frequency. Last, the frequency of anticipated repair, and the associated costs, should be considered.
With those factors in consideration, RDG recommends the following selection guidance:

**Sacrificial or Reusable Crash Cushions:**
- ADT less than 25,000
- low history or expectation of impacts
- installation is greater than 10 ft from roadway
- unlimited repair time

**Low Maintenance and/or Self-Restoring Crash Cushions:**
- ADT of 25,000 or more
- history or expectation of multiple impacts
- location within 10 feet of roadway
- limited repair time (6)

**D. How Crash Cushions Work:**

Crash cushions absorb the vehicle’s energy at a controlled rate; they slow the vehicle to a stopped or almost-stopped position. The vehicle is stopped, or nearly, in a short distance, but the rate of reduction is such that injury to drivers and passengers is avoided or reduced.

Crash Cushions employ one of two methods to transfer the kinetic energy from vehicle to crash cushion:

**Work-Energy Principle:** Crash cushions reduce the vehicle’s kinetic energy so that the vehicle stops. The kinetic energy is converted to other types, like mechanical energy, which then spreads through both vehicle and crash cushion, usually deforming both.

As there are several ways to control the energy of an impact, there is a variety of devices available. Devices that operate under “work-energy” usually feature deformable plastic components that can be re-used. Called “compression” crash cushions, these devices must be anchored to a fixed object in order to resist the force of the impact. (7)

For a list of the types of crash cushions designed with the work-energy principle, see RDG, Chapter 8, Section 8.4.2., Tables 8.5, 8.6 and 8.7. The tables include manufacturers and brand names.

**Conservation of Momentum Principle:** The momentum of the vehicle impact is transferred to a mass of material, usually sand-filled containers.

![Image](figure1.png)

*Figure 1: Conservation of Momentum Principle, early sand barrel crash test*

This type of device does not require an anchor; the vehicle’s kinetic energy is reduced “through momentum transfer by accelerating the sand particles found within the containers or barrels.”

Sand barrel crash cushions are often referred to as “inertial” crash cushions because the material remains inert, or at rest, until an external force, like a vehicle impact, disrupts it. (8)
II.) Sand Barrel Crash Cushions

Sand Barrel Crash Cushions, or sand barrels, fall under the “sacrificial crash cushion” category. In permanent applications, sand barrels shield permanent fixtures like bridge abutments and other fixed objects. They are often used in temporary applications to shield temporary objects like portable concrete barrier. See Figures 2 and 3.

![Figure 2: Permanent Application](image1)

![Figure 3: Temporary Work Zone Application](image2)

A.) Sand Barrels and the Conservation of Movement Principle:

As stated previously, sand barrels slow a vehicle at impact by the conservation of movement principle. Simply, the momentum of the vehicle is transferred to the sand barrels. In theory, this principle does not stop vehicles completely.

Sand barrels typically reduce vehicle speed to 16 km/h, or 10 mph. Any remaining energy is transferred to the sand as the vehicle moves through the array. As vehicle energy is not transmitted through the array, the sand barrels do not require anchoring to a wall or support.

In order to slow the vehicle gradually, which reduces the possibility of killing or injuring drivers or passengers, sand barrels contain different weights of sand when in an array.

The weights are:

- 91 kg / 200 lbs.
- 182 kg / 400 lbs.
- 318 kg / 700 lbs.
- 636 kg / 1,400 lbs.
- 955 kg / 2,100 lbs.

Front barrels contain less sand, to maintain a consistent center-of-gravity height (bumper height) with the vehicle. To maintain center-of-gravity at lesser weights, Inserts are installed in the barrel; these elevate the sand for 91, 182 and 318 kg weights, as shown in Figure 4. To achieve weights of 636 and 955 kg, no insert is required, as shown in Figure 5. (9)

![Figure 4: Sand Barrel with Insert](image3)

![Figure 5: Without Insert](image4)

For the math behind the principle, see RDG, Chapter 8, Section 8.4.3.
B.) Sand Barrel Crash Testing:

In the United States, the current test procedure is the AASHTO Manual for Assessing Safety Hardware (MASH). Devices introduced after January 1, 2011 require testing under MASH procedures.

MASH replaced the National Cooperative Highway Research Report (NCHRP) 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features. However, devices tested under NCHRP-350 procedures were not required to be re-tested under MASH procedures.

Four companies manufacture sand barrels in the USA. Each manufacturer tested their device to Test Level 3 procedures; Test Level 3 tests are conducted with vehicles travelling at 100 km/h, or 62.2 MPH.

![Figure 6: NCHRP-350 Tests 3-40 – 3-44, at Test Level 3](image)

The specific NCHRP-350 tests for sand barrels for Test Level 3, 100 km/h:

- Test 3-40: 0 degree angle, at nose of array, 820C vehicle
- Test 3-41: 0 degree angle, at nose of array, 2,000P vehicle
- Test 3-42: 15 degree angle, at nose of array, 820C vehicle
- Test 3-43: 15 degree angle, at nose of array, 2000P vehicle
- Test 3-44: 20 degree angle, at side of array, 2000P vehicle

Devices that pass either NCHRP or MASH test procedures eventually obtain an Acceptance Letter, issued by the Federal Highway Administration (FHWA), a branch of the United States Department of Transportation. An FHWA Acceptance Letter acknowledges that the device passed the required crash tests. Thus, the device may be sold in the USA, for use on the National Highway System, or wherever federal funding is part of project financing. Each US sand barrel manufacturer has obtained an FHWA Acceptance Letter for their device.
C.) Cost Analysis of Crash Cushions:

We conclude our overview with a discussion about costs associated with crash cushions. Costs include installation costs (purchase plus installation), repair costs, and maintenance costs.

In March, 2012, the Midwest Roadside Safety Facility, (MwRSF), Nebraska Transportation Center, University of Lincoln, NE, USA issued report TRP-03-252-12, *Synthesis of Crash Cushion Guidance*.

The purpose of the study was to “develop crash cushion selection guidelines which would help highway engineers select the most cost-effective crash cushion to be used on various highway scenarios considering a wide range of roadway, roadside, and traffic characteristics.” (10)

The report provides Roadside Safety Analysis; Societal and Direct Costs; Benefit / Cost Analysis; and Application Examples.

To collect cost information, MwRSF researchers issued a survey to 5 state DOT agencies. Results of that survey are below, our Figure 8. Note that installation cost figures also include purchase price.

<table>
<thead>
<tr>
<th>Crash Cushion Type</th>
<th>Crash Cushion</th>
<th>Installation Cost</th>
<th>Repair Cost</th>
<th>Traffic Control Costs</th>
<th>Maintenance Costs</th>
<th>Design Speed, mph (kph)</th>
<th>Length, ft (m)</th>
<th>Width, ft (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redirecting</td>
<td>Quest</td>
<td>$11,510</td>
<td>$133</td>
<td>$1,675</td>
<td>$1,808</td>
<td>Any</td>
<td>19 (5.79)</td>
<td>2.0 (0.61)</td>
</tr>
<tr>
<td></td>
<td>TRAC</td>
<td>$11,400</td>
<td>$3,246</td>
<td>$1,788</td>
<td>$5,034</td>
<td>Any</td>
<td>21.25 (6.48)</td>
<td>2.0 (0.61)</td>
</tr>
<tr>
<td></td>
<td>TAU II</td>
<td>$15,433</td>
<td>$2,391</td>
<td>$1,225</td>
<td>$3,616</td>
<td>Any</td>
<td>23.0 (7.01)</td>
<td>4.0 (1.22)</td>
</tr>
<tr>
<td>Low Maintenance</td>
<td>Quest</td>
<td>$33,017</td>
<td>$2,285</td>
<td>$3,475</td>
<td>$5,760</td>
<td>$45 (72.4)</td>
<td>18.0 (5.49)</td>
<td>2.0 (0.61)</td>
</tr>
<tr>
<td></td>
<td>REACT350</td>
<td>$36,067</td>
<td>$1,727</td>
<td>$925</td>
<td>$2,652</td>
<td>$45 (72.4)</td>
<td>27.0 (8.33)</td>
<td>2.0 (0.61)</td>
</tr>
<tr>
<td></td>
<td>SCI</td>
<td>$19,371</td>
<td>$48</td>
<td>$330</td>
<td>$598</td>
<td>$45 (72.4)</td>
<td>13.5 (4.11)</td>
<td>2.0 (0.61)</td>
</tr>
<tr>
<td>Nonredirecting</td>
<td>Sand Barrels</td>
<td>$2,540</td>
<td>$1,880</td>
<td>$1,225</td>
<td>$3,105</td>
<td>Any</td>
<td>16.5 (5.03)</td>
<td>6.0 (1.83)</td>
</tr>
</tbody>
</table>

Figure 8: MwRSF Crash Cushion Costs (11)

III.) Conclusion:

MwRSF researchers stated that sand barrels enjoy much lower costs than other types of crash cushions, but replacement costs could prove significant, based on impact frequency. Redirecting, sacrificial crash cushions, in their analysis, proved the most cost-effective crash cushion in their application examples.

However, as the MwRSF summary above shows, sand barrels enjoy a significant cost advantage, so much so that they could be replaced several times over before exceeding the costs of the other types.

Too, sand barrels do not require anchoring or support, unlike compression crash cushions. This reduces replacement and maintenance costs. Most importantly, workers can replace units quicker, reducing their exposure to traffic.

Last, with 50 years of installations, their reputation as a device that saves lives has been long established.

Crash cushions should be the first option specified to shield fixed objects on roadway projects.
References:


2.) *ibid*, Chapter 8, Section 8.4.2.1, page 30

3.) *ibid*, Chapter 8, Section 8.4.2.3., page 41

4.) *Minnesota Department of Transportation (DOT)*, *Traffic Engineering Manual*, Chapter 8, Section 8.5.10, page 8-17, Minnesota DOT, Minneapolis MN USA, 2009

5.) *ibid*

6.) *Roadside Design Guide 4th Edition*, Chapter 8, Section 8.4.5.5., page 65

7.) *ibid*, Chapter 8, Section 8.4.1.1., page 27

8.) *ibid*, Chapter 8, Section 8.4.1.2., page 27

9.) *ibid*, Chapter 8, Section 8.4.3., pages 48-49.

10.) *Synthesis of Crash Cushion Guidance*, page 2, Schrum, Albuquerque, Sicking, et al, Midwest Roadside Safety Facility, Nebraska Transportation Center, University of Nebraska, Lincoln NE, March 2012

11.) *ibid*, page 15
**PAPER TITLE** | The use of computer simulation for the development of Vehicle Restraint Systems  
---|---  
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**KEYWORDS:**  
Road safety, road restraint systems, finite elements, crash tests, EN1317.

**ABSTRACT:**  
The object of this paper is to briefly illustrate the value of numerical simulation to improve the development, the certification and the installation of Vehicle Restraint Systems. Predictive simulations are useful during the design phase of a new product, be it, for instance, a safety barrier or a crash cushion; they can also be used to achieve the certification of an already tested system subject to partial modifications, as prescribed by the reference norm EN1317, or to obtain a CE marking.  
From full scale models to local tests, through computer simulations it is possible to evaluate and investigate all the potential and real technical constraints like, for instance, soil and steel characterization, the behavior of the VRS if installed on a bridge or along a curved road, the influence of the installation length and sensibility of the product to the variation of the impact conditions.  
Computer simulations can also be used to reconstruct road accidents.
The use of computer simulation for the development of Vehicle Restraint Systems

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1. INTRODUCTION

In the European Union over 300 million vehicles circulate on a road network of approximately 5 million kilometers. The societal impact of road accidents, fatalities and injuries is estimated to be around 2% of the EU GDP, or in other words, around 250 billion euros. Injuries and fatalities due to road accidents are a problem that can be considerably addressed if the necessary attention is given to the prevention strategies and solutions.

Road restraint systems can be considered as the most “flexible safety device” possible: they are designed to withstand a crash from different kind of vehicles in different conditions: according to their containment level, they are tested both for a small city car or a large family van, small to heavy trucks or coaches, with the possibility to equip them with a motorcyclist protection system (MPS) to further extend their protection to a particularly affected class of vulnerable road users.

Road safety is based on a three pillars approach, by focusing on the vehicle and its equipment, the driver (the so called human factor) and last but not least, the infrastructure and the environmental factors: all these are considered before, during and after an injury.

In turn, infrastructure safety can be separated into active safety measures, whose role is to ensure, as far as possible, that the driver maintains control of his vehicle through appropriate guidance (e.g. road markings and signs) and passive safety measures, whose role is to protect drivers once they have lost control of their vehicle and, finally, to protect drivers from their own human mistakes.

These concepts are summarized in the well-known Haddon matrix, reported in Figure 1:

![Haddon Matrix](attachment:image)

**Figure 1: Haddon Matrix**

The Haddon Matrix should be a useful tool to evaluate the relative importance of different factors and design intervention. [1]
To help understand the matrix and its symbols, the third column is explained: to prevent a crash that could lead to injuries or even death, it is possible to act on the road and its signals, prescribing the right speed limits for instance. Once the crash is happening, the infrastructure must minimize its consequences by using crash-protective roadside objects. After the crash the road infrastructure has to offer rescue facilities and the possibility of re-organize the traffic.

Road Restraint Systems are one of the most efficient and cost-effective road infrastructure solutions, which can reduce the impact of a road accident and the number of fatalities and injuries for the vehicle passengers. Being the safety of the roads such an important topic, a tool like numerical simulations can help to improve the development of all the products.

1.1 - WHAT IS A ROAD RESTRAINT SYSTEM?

A Road Restraint System is a safety product, which aims at reducing the consequences of accidents of an errant vehicle. Road restraint systems can be divided in [5]:

- Road safety barriers – the road barriers are placed along the roadside or on the central reserve; their role is to prevent errant vehicles from crashing on roadside obstacles, and to retain them safely.
- Crash cushions – the crash cushions are collapsible structures that prevent vehicles (usually cars) from impacting specific hazardous sections (e.g.: the beginning of the central reserve). They safely stop the vehicle, avoiding worse consequences.
- Terminals for road safety barriers – Terminals are the ending part of a safety barrier; their role is to avoid those parts from becoming dangerous points for vehicles.
- Motorcycles protections systems – MPS represent an integrated system or an upgrade which, if applied on a road safety barrier, can reduce the consequence of impact for a motorcyclist after falling.
- Transition between two safety barriers – Transitions are products which connect two safety barriers, guaranteeing structural continuity and a correct passage from the performance of the first barrier to the following one, without creating black spots in those critical points.

Each of those products have to comply with several safety requirements, which take into account the safety of the occupants involved in the crash as well as the safety of incoming traffic, both on the same lane and on the opposite one, depending on their location (lateral/central).

To assess those requirements, crash tests must be performed on each of those products; they aim at recreating ideal situations representative of the worst possible real-case that may happen in real-life, considering the “state-of-the-art” of crash-testing technology, the repeatability of the tests and, of course, the need to assess reliable safety features.

1.2 – WHY NUMERICAL SIMULATIONS?

Thanks to numerical simulations it is possible to study a product before it exists in reality, saving costs and money. Since several scenarios can be virtually studied, the probabilities of succeeding a crash test should increase, at the same time optimizing the design, reducing the weight and increasing the performance of the products.

Once a device has been tested, as prescribed by the norm EN1317, it can be modified and certified without the necessity of affording the costs of another real test, but proving that it can achieve specific performance using the results of the numerical simulations.

All the possible impact conditions can be easily studied, like: impact speed and angle between the allowed tolerances, effects of the interaction with different type of soil (soft, hard, concrete if on bridges), behavior of a transition between two different restraint systems.

If a proper library is available, the same impact could be studied using different vehicles, representative of the real counterparts, to evaluate how the behavior changes.

Simulations can also be a useful tool to reconstruct what happened during an accident, to investigate its causes and understand what went wrong.
2. USE OF COMPUTER SIMULATION

2.1 - NEW PRODUCT DEVELOPMENT

As showed in Figure 2, by using the numerical simulation all the phases of the development of a product can be studied.

![Figure 2: Product development](image)

From the drawings, a CAD model can be realized and used as starting point to create a finite element model; thanks to the powerful parametric interfaces, once a model is done, any modification can be easily achieved by directly changing the needed parameters, and not re-doing the model from zero. Simulations can be iteratively done modifying each time the design model, until the desired performances are achieved.

The objectives can be different, but all can be studied: if the weight is a constraint, it can be measured and the product modified according to the specifications.

In terms of performances, the norm EN1317 [2] defines different criteria:

- the severity of the impact, through the ASI index, that is directly dependent on the accelerations on the vehicle;
- the working width;
- the dynamic deflection.

![Figure 3: Working width and dynamic deflection](image)
Keeping the same containment level of the VRS, the ASI can be reduced, making the impact less violent; the lateral displacement can be decreased using optimized geometries, and the weight can be reduced.

Figure 4: N2 systems comparison

In Figure 4 is highlighted how keeping constant the working width, the weight can be significantly reduced performing only numerical simulations, without the need of real crash tests.

Figure 5: Optimization process
2.2 – CERTIFICATION

The recent versions of the part 5 of the norm EN1317 [2] allows the certification of modified products only performing numerical simulations. Once a product has passed the necessary crash test and a calibrated numerical model is available, such virtual model can be modified and studied; no new real crash tests are needed to certify the behavior of the product, since the simulation is considered a valid and correct representation of the reality.

A typical example consists in certifying the same road safety barrier, but changing only the posts distance, as showed in Figure 6.

<table>
<thead>
<tr>
<th>What you have:</th>
<th>What you want:</th>
<th>What you need:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• A product that passed the necessary crash-tests</td>
<td>• adapting your product without having to perform new crash tests</td>
<td>• A simulation of the modified product using proven models according to EU best-practices</td>
</tr>
</tbody>
</table>

For the posts distance of 1.33 and 2 meters a crash test has been performed and a numerical model exists only for the first one and it reproduces correctly the crash, satisfying the criteria prescribed by the EN1317 not only in terms of correlation of the performances (ASI, Working width, dynamic deflection, etc.…) but also from a numerical point of view, since the stability of the model has to be verified too: energies variations must be limited, hourglass energy less than a certain amount, mass scaling not above a critical value, etc. …

The virtual model is then changed, adjusting the posts distance to 1.5 meters: the simulation is performed, without varying any other parameter of the calibrated and validated model; the obtained results are considered reliable, and they can be used to certify the performances of the modified product.

The hypothesis to achieve a perfect correlation, as prescribed by EN1317, between numerical simulations and reality are quite strict; the model must represent with high fidelity the reality.

For instance, the norm imposes a range of tolerances for the dimensions and the mass distribution of the numerical model of the vehicle used; the following table resume the specifications of the one used to achieve the mentioned calibration:

<table>
<thead>
<tr>
<th>Real Vehicle</th>
<th>Vehicle model</th>
<th>EN1317 Specifications</th>
<th>EN1317 Tolerance</th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>7.2 m</td>
<td>7.22 m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Width</td>
<td>2.52 m</td>
<td>2.52 m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wheel track</td>
<td>1.74 m</td>
<td>1.96 m</td>
<td>2 m</td>
<td>±15%</td>
</tr>
<tr>
<td>N of axles</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wheel radius</td>
<td>0.44 m</td>
<td>0.45 m</td>
<td>0.46 m</td>
<td>±15%</td>
</tr>
<tr>
<td>Wheel base</td>
<td>4.03 m</td>
<td>4.03 m</td>
<td>4.6 m</td>
<td>±15%</td>
</tr>
<tr>
<td>Height (platform)</td>
<td>1.44 m</td>
<td>1.08 m</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Looking at the first row, it is clear that the norm does not impose any specification, but of course the more the model represents the reality, the better will be the results of the simulation.

This does not apply only to the vehicle, but to all the modeling choices; sometimes is up to the analyst skills to decide which are the best ways of representing the reality.

If it is known, from experimental evidence, that failure, of any kind, does not occur, then it could be a reasonable approximation to not include it in the model; on the other hand, if any of the critical components of the VRS could be subject to rupture, then the numerical model used to represent them must refer to the state of the art.

A simple criterion based on elements elongation may be accurate in a uni-axial test, but due to the complexity of the state stress because of the variety of solicitations happening during a crash test, a triaxiality model could also be required to achieve good results. [6]

In theory, and going a little to the extreme, the only limitations of numerical simulations are computational time and the amount of hours spent calibrating all the parameters needed to perform the simulation.

While performing a calibration of a real crash test, the first thing that has to be adapted are the impact conditions; since it is difficult to perfectly match speed and impact angle, these are allowed to deviate, within certain tolerances, from the nominal values.

<table>
<thead>
<tr>
<th>Measure</th>
<th>C-T</th>
<th>V-T</th>
<th>EN1317-5</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic deflection [m]</td>
<td>0.9</td>
<td>0.78</td>
<td>&lt;0.18</td>
<td>0.04</td>
</tr>
<tr>
<td>Normalized dynamic deflection [m]</td>
<td>0.8</td>
<td>0.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working Width [m]</td>
<td>0.9</td>
<td>0.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normalized working width [m]</td>
<td>0.9</td>
<td>0.86</td>
<td>&lt;0.18</td>
<td>0.04</td>
</tr>
<tr>
<td>Class of normalized working width</td>
<td>W3</td>
<td>W3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max permanent deflection [m]</td>
<td>0.6</td>
<td>0.54</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 8: Crash test dynamic

Figure 9: Plastic strain fringes
In parallel to the physical comparison, also the numerical quality of simulation is regulated:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Change (%)</th>
<th>Pass?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total energy of the analysis solution must not vary more than 10%</td>
<td>0</td>
<td>YES</td>
</tr>
<tr>
<td>Hourglass energy of the analysis solution is less than 5% of the total internal energy at the beginning of the run</td>
<td>0</td>
<td>YES</td>
</tr>
<tr>
<td>Hourglass energy of the analysis solution is less than 10% of the total internal energy at the end of the run</td>
<td>2</td>
<td>YES</td>
</tr>
<tr>
<td>Mass added to the total model is less than 5% of the total model mass at the beginning of the run</td>
<td>0</td>
<td>YES</td>
</tr>
<tr>
<td>The part/material with the most mass added had less than 10% of its initial mass added</td>
<td>0</td>
<td>YES</td>
</tr>
<tr>
<td>The moving parts/materials in the model have less than 5% of mass added to the initial moving mass of the model</td>
<td>0</td>
<td>YES</td>
</tr>
<tr>
<td>There are no shooting nodes in the solution</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>There are no solid elements with negative volumes</td>
<td>NO</td>
<td>YES</td>
</tr>
</tbody>
</table>

Considering a TB11, via numerical simulations it is possible to evaluate the effects of the posts distance on the ASI parameter:

![Figure 10: ASI comparison](image)

It is then possible to see the difference between the two solutions: with posts each 2 meters the accelerations are higher, compared to a solution with 4m between each posts.
Figure 11: Certification process in Europe

Figure 11 summarizes the whole certification process in a schematic way, as it can be done in Europe according to the EN1317.

2.3 – DESIGN ISSUES

Probably, the field where numerical simulations exhibit their full potential is in the study of the influence of determined parameters on the behavior of the product.

For instance, how could the soil behavior affect the performances of vehicle restraint system? Proceeding via real crash test would be very expensive and difficult, since several trials should be performed, and moreover the preparation of the different conditions may take time.

Instead, with a calibrated numerical soil model, several scenarios could be evaluated simply by changing different parameters and performing analysis.

Figure 12: Post reinforcement effects

In Figure 12 the effects of reinforcement on the posts are studied, meanwhile in Figure 13 it is highlighted how the soil behavior affects the performances of a road safety barrier.
A softer soil, typically, leads to bigger posts displacement and consequently minor deformations; globally the system is expected to be less rigid. But this is not always true, because a hard soil could help the disconnections between posts and beam elements of the VRS: in such case the majority of the energy is absorbed by the longitudinal elements that could significantly deform and cause a higher lateral displacement of the system.

It is in such cases that the versatility of numerical simulation gives a decisive contribution to the design of the product, allowing studying several cases significantly different between them.

Other scenarios may even be impossible to study in real conditions, due to the severe consequences in case of an unexpected failure: a typical example is the investigations of the loads transmitted by a VRS to the structure of a bridge.

The numerical modeling is simple, but performing a real crash test would be almost impossible; and even if the crash could be performed, accurately collecting all the data would be another great challenge; instead, through numerical simulation all the needed information are easy to gather, in all the possible scenario.

Figure 14 shows the typical situations that can be investigated via numerical simulation and that, at the same time, are expensive and complicated, when possible, to realize in reality.
2.4 – ACCIDENT RECONSTRUCTION

In case of an accident, the scenario can be numerically reproduced, to investigate the causes and to improve the design, to avoid that a similar event may happen again in the future.

Figure 15: Accident reconstruction

Figure 16: Frontal impact of a N2 barrier
3. CONCLUSIONS

The numerical simulation, if used properly, can be a powerful tool for the development of a product; together with the experience and the results of real crash tests it is possible to create finite element models that are an accurate reproduction of the reality.

After a numerical study, the chances of succeeding a real crash test should be higher, since the product is already optimized and, on the paper, it satisfies the desired performances.

The advantages in terms of reduced costs and time to have the desired results are significant; in theory, every possible condition that exists could be simulated and investigated.

The topic of numerical simulation is wide and not yet fully developed nowadays: each tool used can be the object of dedicated research project, to evaluate all the available approaches to virtually represent the reality.

Of course, to have meaningful results the tools used during the modeling phase have to be constantly updated: the materials, for instance, should always be tested in real, to obtain curves and values to use as input for the finite element model.

A numerical model based on wrong physics assumptions is meaningless: the analyst should always keep in mind the initial hypothesis and critically interpret the results.
4. REFERENCES


NEW TECHNOLOGIES FOR ROAD SAFETY AND MAINTENANCE: SHOTBLASTING

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Athanassios Spondylidis, Architect, ex Vice Governor of Infrastructures, Region of Attica, Athens Greece

PREFACE

The method of Shotblasting is a new technology process that enables roads to increase their non-slip characteristics, through increased roughness on the surfaces. It is applied with a machine that "shoots" high speed steel balls on the pavement. Consequently, it creates a rough surface on the asphalt, greatly increasing the skid resistance (Retexturing). Already, this method is widely applied in many countries in the world, with excellent results. The revolutionary technology of Shotblasting, can increase the anti-slip characteristics of all road surfaces, including new ones [9].

1. INTRODUCTION

Skid resistance is the most important surface characteristic; it is associated with both pavement serviceability and road safety. Its importance and complexity have increased over the years due to increased demands for safer roads and the desire for greater road user comfort. Pavement surfaces must ensure adequate levels of skid resistance for the vehicles in order to perform in safety. It is a reality that as the skid resistance of a pavement surface decreases the accident rate increases. On wet pavements, the road safety issue is amplified because of the reduction of contact between the tires and the road, as the water acts as a lubricant.

The resistance to skidding is the fundamental requirement that road engineers must consider in pavement design to provide a safe surface. Skid resistance is an aspect of regular pavement condition monitoring and road authorities must be proactive in efficient and effective control management.

With the passage of time due to traffic loads, weather conditions and the aging of materials, pavement maintenance or rehabilitation is required in order to preserve the pavement surface to its initial level or even better. Pavement preservation is very important, but rehabilitation budgets many times cannot keep up with the demand of an aging infrastructure. Road authorities have to search for effective low cost methods to maintain surface skid resistance at acceptable levels that, if possible, require limited need of road closure. One of the most efficient preservation methods is the "shot blasting" technique.

The present paper is a presentation, but also investigation, looking the effectiveness and performance of the shotblasting method for the retexturing of asphalt pavement surfaces, on site, but also linked with road safety. Skid resistance and micro texture as well macro texture measurements were performed before and after the application of the shot blasting method along deferent road sections. The input data was analyzed in order to investigate the impact of the method on skid resistance and pavement micro and macro texture, but also investigate the reduction ratio of road accidents, at the same sites, comparing the skid resistance results “before and after” with the road accident certificates that road authorities and traffic police proclaimed, before and after shot blasting. The main findings and results are presented.

2. SKID RESISTANCE

Skid resistance has two major components: adhesion and hysteresis. Adhesion results from the shearing of molecular bonds formed when the tire rubber is pressed into close contact with pavement surface particles. Hysteresis results from energy dissipation when the tire rubber is deformed when passing across the asperities of rough surface pavement [3].

Macro texture is the space or void between the aggregate particles (Figure 1). It is the most important characteristic of the road surface roughness, which allows the water to drain away from surface and greatly contributes to skid resistance in wet conditions. Good texture depth is also necessary to allow mechanical deformation of the tire (hysteresis) which absorbs kinetic energy.
Macrotexture is the space or void between the aggregate particles [9]. Micro texture is the fine component of surface texture formed by the tiny interstices on the surface of the aggregate particles. It is the main contributor for providing grip or skid resistance to the tire (Figure 2). Micro texture is measured by SRV using the British Pendulum Tester. Micro texture is defined by wavelengths of 1mm to 0.5mm (0.0004in to 0.02in) and macro texture is defined by wavelengths of 0.5mm to 50mm (0.02in to 0.2in).

Figure 1. Macrotexture is the space or void between the aggregate particles [9].

Figure 2. Microtexture on the surface of the aggregate particles [9].

3. SKID RESISTANCE MEASUREMENT TESTS ACCORDING UNI EN

Measurement of pavement surface macro texture depth using the volumetric sand-patch technique UNI EN 13036/1: Testing points are identified on the road surface, along the trajectory of maximum speed on which a vehicle runs, to determine macro texture in accordance with the standard UNI EN 13036/1. The method requires spreading a certain volume of natural siliceous sand, clean and dry, with grain size between 0.160-0.315 mm, on the surface to be tested, so as to shape a maximum circular area. The ratio between the volume of the sand and the covered area, represents the average value of roughness (macro texture depth) expressed as the average sand patch diameter (Figure 3).

Figure 3. Measurement of pavement surface macro texture depth using the volumetric sand-patch technique UNI EN 13036/1.[9]
Micro texture test by UNI EN 13036/4 to determine sliding friction with portable pendulum (British Pendulum Skid Friction Tester), (Figure 4): Defines the slipperiness of the road surface through the energy loss due to sliding of a moving rubber head mounted at the end of the pendulum. The pendulum is dropped from a horizontal position on the surface, previously wetted with water. Values are expressed in Skid Resistance Value (SRV) by rule UNI EN 13036/4. The test simulates slipping of a locked vehicle wheel, which travels with a speed of 50 km per hour on an asphalt road and in wet conditions.

Figure 4. British Pendulum Skid Friction Tester. UNI EN 13036/4. [9]

4. SHOTBLASTING

Shotblasting has been introduced as an innovative, low cost method, for increasing pavement skid resistance properties. It is a process that relies on a machine that propels steel shots particles onto the pavement surface and blasts away contaminants, such as excess bitumen, and finally retexturing of pavement surface. The process is fully controlled, safe and environmental friendly. It uses no water, chemicals or solvents, emits no pollutants or dust to the atmosphere and the removed material can be fully recycled. The shotblasting system essentially consists of the following components: shot propelling apparatus, vacuum system, magnetic separator, residue container and follow-on magnetic brush/broom to pick up any debris that might have been left by the shotblasting system [10] (Figures 5-6).

Figures 5-6. Typical shotblasting system. [9]

Steel shot is fed by gravity through a control valve into an impellor. The impellor turning at high speed throws the steel shot through an adjustable opening at high velocity and at a specific angle on to the surface over which the self propelled machine is travelling. The steel shot impacts the surface and bounces off so that material from the surface, whether contaminants, coatings or the surface material itself, is abraded and loose material together with the shot is drawn up into the machine by the airflow created by the vacuum unit [3]. Brush seals enclose the blast head to the surface and air is drawn in through and under the brushes from the surface to ensure no shot or material from blast head escapes into the atmosphere. The debris and shot is drawn up into the separation chamber and by a dual cyclone and magnetic separation process the debris is
drawn off to the dust collector and the shot is recycled back to the blast head. The strength or degree of blasting required is infinitely variable. Accurate control of the blast pattern and the degree of removal or texture created is controlled using various machine setting and operational practices [3]. For road works the method is applied with a truck machine that "shoots" high speed steel shots on the pavement (Figure 7).

Figure 7. Shot blasting truck machine for road works.[9]

5. MAIN BENEFITS of SHOTBLASTING

Increases dramatically road safety because reduces immediately and impressively road accidents, in some cases more than 80%-90%. Economy of price / sq m, which is much lower compared to the conventional maintenance method, about 1/10 cheaper of new asphalt layer. Productivity at 1,5km / h, means that comes to benefits of 1,500sqm per hour, about 10 - 15,000 sqm per day. Free road with no interruption necessary because traffic is normally conducted.

Environmentally friendly because it does not pollute the environment, the application eliminates wastes, since the machine absorbs all of them. A separator divides recyclable metal shots from the blasting residues, and they are reused in the new cycle process of "shot". Waste is transferred to the rear of the truck in special “big-bags”. With only a single pass, the machine leaves the road ready for use. Increases macro and micro texture of the road pavement and as result prolongs life of the pavement for many years without needing a new asphalt layer (at least 4-5years). Removes the rubber on airport runways and erases the old road markings. [9]

6. WORK SITES MEASUREMENTS

In order to investigate the effectiveness of the shot blasting method, micro texture as well as macro texture measurements were performed on tree deferent kind road sections (3 cases): motorway, highway, high speed city avenues. Both before and after the application of the method on effective work sites that were placed in Greece. Specifically, both of the measurements (by UNI EN 13036/4 & 13036/1) were applied at different sections, of every kind of road, with lengths that range from 50 m to 0,5 km. Skid resistance measurements were performed using the UNI EN tests as analyzed (paragraph 3). Classification of skid resistance values (SRV) are presented on Figure 8. It is noted that measurements were performed in every case under suitable climatic conditions (no rain) so that the results were accurate and valid. Also, the sites where controlled again in different time periods after shot blasting, from 3 months to 3 years, to control the possible degradation of skid resistance and the effectiveness of the method. The progress of time control of the tree cases was: case 1 / immediately after shot blasting, case 2 / 3 months after shot blasting, case 3 / 3 years after shot blasting. At least but most, certificates where asked from the road maintenance authorities and the traffic police authorities of the sites, to control the effect of the skid resistance improvement on road accidents number take place, both before and after shot blasting, in time periods not less than six (6) months.
7. DATA ANALYSIS AND CONTROL OF RESULTS

The collected data was analyzed in terms of: a) Skid Resistance Value (SRV) when the UNI EN 13036/4 used and b) average texture depth TD (mm) when the UNI EN 13036/1 used, as defined previously and c) GN (Grip Number) with the measured skid resistance before (GNb) and after (GNa) Shotblasting.

Case 1: High speed city avenues, Athens Greece, measurements immediately after Shotblasting. In this case, as it can be seen in Figure 9, the texture depth TD value is much higher after shot blasting than those before, average value show 0.32mm before and 1.12mm after shot blasting (3.5 times deeper macro texture). Also there is a great SRV increasing, as it can be seen in Figure 10, the SRV average value show 36 SRV before and 89 SRV after shot blasting (2.5 times better micro texture).[5]
Case 2: Ring Road Motorway, Athens Greece, measurements 3 months after Shotblasting. In this case, as it can be seen in Figures 11-12, the GN is much higher three months after shot blasting than GNb. Skid resistance increased and remain at 76.5% higher than the initial condition. [1]

Figures 11-12: Ring Road Motorway, Athens Greece, measurements 3 months after Shotblasting [1]

Case 3: National Highway, Tripolis – Sparti Peloponnesse, Greece. Measurements three (3) years after Shotblasting. Also in this case there are great SRV average values that confirm the importance of the method also after long time periods. The SRV average values show 32 SRV before and 61 SRV after shot blasting (up to 90.50% of the initial state) [5].

8. SHOTBLASTING AND ROAD SAFETY

In addition to “on site” measurements made on the above mentioned roads, the survey went a step further. Certifications by road maintenance services [1],[4],[7] and competent traffic police [8] requested, to check the real effect of the method on road safety, particularly at the sections where shot blasting was applied, to check eventual reduction of road accidents. The road accidents where been recorded several months before the implementation of the method, as well as at least same time period after shot blasting. In each site it has been calculated the ratio of accidents per month, in order to make the correct mapping of the potential reduction (figure 13). The results where astonishing and they have been presented at the ERF’s Technical Conference on Road Infrastructure & Safety Equipment (Athens, 12-13 February 2015).[6]
9. CONCLUSIONS

Skid resistance is related in both micro and macro texture. The shot blasting method had proved that has the advantage of increasing both these properties greatly. The combination of both properties brings the perfect result, perhaps even better than a new asphalt layer. Also, asphalt layers containing largely limestone aggregates, which are often presented in Greece, have the advantage of higher macro texture growth after being shot blasted. On the other hand, the “hard” asphalt mixtures have the advantage of increasing greatly also micro texture. The results show that immediately after application of the method, there is an increase of total skid resistance factors, enormously up to 200% of the initial state. After the first three months there is a decline from baseline (immediately after shot blasting values) up to 25% and after this time, a stabilization of prices for at least three years, with prices anyway to be far greater from the original state before application. Furthermore, certificates of services that control and maintain these specific roads are proving a direct link of skid resistance and road safety. Good macro texture means hysteresis, good micro texture means grip. Both of them mean safety. It turns out that the skid resistance is the key player in infrastructure to reduce road accidents. Shotblasting is the finest tool for the immediate resolution of the road safety issue and as so is very promising.

REFERENCES

1 INTRODUCTION

A Safe pan-European road network is the backbone of a sustainable transport system capable of delivering fast, affordable and reliable transport solutions in Europe. The free movement of people and goods is a noble European goal and the decision by EU nations to develop trans-European networks is a practical expression of it. EU nations have committed themselves to ensure “...the sustainable mobility of persons and goods under the best possible social, environmental and safety conditions” (European Parliament, 1996).

Safety is the primary concern of any European traveller exercising “freedoms” guaranteed by the EU integration process. Combining freedoms with safety transnational approach brings greater value because it:
- Improves accessibility through making access across borderless Europe safer;
- Encourages the introduction of coordinated methodologies and policies involving national and international stakeholders;
- Provides opportunity for convergence of current practice reinforcing the needs for harmonisation at EU level;
- Creates a system of benchmarking by encouraging cooperation and involving countries with differing road safety performance and different ways of addressing varying risk on roads.

Aim of this paper is to present the results of road inspections, safety ranking and countermeasures evaluation for a 3,600 km part of the major road network in Greece. These results are only a part of the analysis of almost 19,000Kms of the Trans European Road Network (TEN-T) in 14 countries in South East Europe, which was performed within the framework of the SENSoR Project, according to the internationally recognized iRAP protocols.

2 THE SENSoR PROJECT

SENSoR (South East Neighbourhood Safer Roads) builds on outstanding cooperation between automobile clubs, universities and road authorities. Having been co-financed by the South East Europe (SEE) Transnational Cooperation Programme and the European Union, the 2-year project brought together 14 countries – Greece, Slovakia, Hungary, Slovenia, Republic of Moldova, Serbia, Former Yugoslav Republic of Macedonia, Bosnia and Herzegovina, Croatia, Albania, Montenegro, Bulgaria, Romania and Ukraine.

The project was launched in September 2012 and completed in November 2014. It included the road survey, coding, analyses and reporting of Road Assessment Programme road safety assessments of 19,000kms of routes (including around 4,000km donated from earlier surveys in Moldova and Ukraine in the above-mentioned countries and more than 27,000km of Risk Mapping using fatal and serious crash data.
3THE iRAP PROTOCOLS

The main objective of the iRAP method is the improvement of the road users’ safety by proposing cost-effective investment plans. The most crucial point in the iRAP is that engineers and planners in developed countries, for over twenty years, have adopted an underlying philosophy of designing a forgiving road system to minimize the chances of injuries when road users make mistakes that result in crashes as Hills, Baguley & Kirk (2002) mention. The method indicates that the severity of a road accident can be reduced through the intervention at the sequence of events happening during this accident. As it is known, an injury accident results from a chain of events, starting with an initial event, probably resulting from several factors, which leads to a dangerous situation. The basic idea is to intervene at any point of this chain, in order to reduce the kinetic energy of all road users, who are involved, in the accident to a tolerable level. Lynam (2012) supports that such an intervention will not reduce the number of accidents, but the severity of injury.

The initial step for the implementation of the iRAP method is the inspection and record of the infrastructure elements of a road network, which relate to the road safety. The record leads to the quantification of the safety that a road section provides to its users by awarding safety scores (Star Rating Scores). The Star Rating Scores express the safety capacity of a road section in a 5-Star scale. This quantification aims at identifying the most appropriate countermeasures, which will increase the infrastructure’s road safety score. The Safer Roads Investment Plan (SRIP) includes all the countermeasures proved able to provide the greater safety capacity and maximize the benefit over spent cost of the planned investments. Thus, the SRIPs are considered as a valuable tool for the authorities, stakeholders and investors in order to decide for the most cost-effective and efficient road infrastructure investments.

3.1 Measuring the road infrastructure safety

The assessment of the road safety requires the road safety inspection (RSI) of the road elements and the assignment of a safety score to them. The inspection is conducted by visual observation and record of the road infrastructure elements which are related -directly or not- to road safety and have a proven influence on the likelihood of an accident or its severity. The iRAP uses two types of inspections; the drive-through and the video-based inspection. During the first one, the record of the infrastructure’s elements is performed manually, with the help of specialized software, while during the second, a specially equipped vehicle is used, so as the recorded video to be used for a virtual drive-through of the network and an automated identification of the infrastructure’s elements.

Following the RSI, the Road Protection Score (RPS) is calculated. The RPS is a unit-less indicator, which depicts the infrastructure’s safety capacity for each road user type and it is calculated for 100m road sections. Road user types are considered the car occupants, the motorcyclists, the bicyclists and the pedestrians, who may be involved in road accidents. For each road user type and for each 100m road section the respective RPS is calculated as follows (Lynam, D., 2012):
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September 15-18, 2015 – Istanbul Turkey

\[
RPS_{n,u,c} = \sum_c RPS_{n,u,c} = \sum_c L_{n,u,c} \times S_{n,u,c} \times OS_{n,u,c} \times EFI_{n,u,c} \times MT_{n,u,c}
\] (1)

where “n” is the number of 100m road section, “u” the type of road user and “c” the crash type that the road user type “u” may be involved in. The following variables are taken into consideration: L: the Likelihood that the “i” crash may be initiated, S: the Severity of the “i” crash, OS: the degree to which risk changes in relation to the Operating Speed for the specific “i” crash type, EFL: the degree to which a person’s risk of being involved in the “i” type of crash is a function of another person’s use of the road (External Flow Influence), MT: the potential that an errant vehicle will cross a median (Median Traversability).

3.2 The Star-Rating process

The aim of the Star Rating process is the award of the “n” 100m road sections with Stars, depicting the safety offered to each of the “u” road users’ types. The Star Rating system uses the typical international practice of recognising the best performing category as 5-star and the worst as 1-star (5-star scale), so that a 5-star road means that the probability of a crash occurrence, which may lead to death or serious injury is very low. The Star Rate is determined by assigning each RPS calculated to the Star Rating bands. The thresholds of each band are different for each road user and were set following significant sensitivity testing to determine how RPS varies with changes in road infrastructure elements. The assignment procedure leads to the development of a risk-worm chart, which depicts the variation of the RPS score in relation to the position (distance from the beginning) on the road under consideration. The final output of the Star Rating is the Star Rating Maps, in which the “n” road sections are shown with different colour, depending on their Star award (5-star green and 1-star black).

3.3 Developing the Safer Road Investment Plans (SRIPs)

The development of the most appropriate SRIP presupposes the assessment of the number of fatalities and serious injuries that could be prevented for each 100m road section on an annual basis when a set of countermeasures is applied. The number of fatalities is calculated as follows:

\[
F_n = \sum_u \sum_c F_{n,u,c}
\] (2)

where “n” is the number of the 100m road section, “u” the type of road user, “c” the crash type that the road user “u” may be involved in and F the number of fatalities that can be prevented on a time period of 20 years, given that a specific set of countermeasures is applied.

The F number is related to four main factors: (1) the safety score of the specific road section, (2) the “u” road users flow, (3) the fatality growth, which indicates the underlying trend in road fatalities and (4) the calibration factor, which inserts the actual number of fatalities that occur in the specific road section. The calculation of this factor presupposes the existence of similar crash data.

The assessment of the number of serious injuries that could be prevented for a 100m road section is a function of the \(F_{n,u,c}\) value and the ratio of the actual number of serious injuries to the actual number of fatalities to the relevant number of fatalities. In case of lack of appropriate data, the competent Authorities should estimate this actual number as previously, or as the ratio of 10 serious injuries to 1 death, which is proposed by McMahon and Dahdah (2008).

The next step in establishing the SRIPs is the identification of the most appropriate countermeasures. Countermeasures are the engineering improvements that the road authorities should take so as to reduce the fatalities and serious injuries rates. Each countermeasure is characterized by its trigger sets and its effectiveness for each of the 100m road sections. Each trigger set describes all the cases in which this certain countermeasure can be used. The effectiveness is calculated according to the number of fatalities and serious injuries that can be prevented in this section and the RPS of this section before and after the
application of the countermeasure. It is important to mention that in the case that multiple countermeasures act on a certain road section, the total effectiveness is not the simple sum of each countermeasure’s effectiveness. Instead, a reduction factor should act, which calibrates the total effectiveness.

The procedure of selecting the most appropriate countermeasures is the basis for the techno-economic analysis of the investment plan and aims at the calculation of the Benefit-Cost ratio (BCR) for each countermeasure. The economic benefit is considered as the benefit of preventing a death or a serious injury. The calculations are conducted following the assumptions that the cost of a human life is 70 times the GDP per capita, the cost of a serious injury is the 25% of the cost of a human life and the ratio of 10 serious injuries for 1 death, if more accurate information is not available. In Greece, according to research studies, the cost of a human life is estimated to 1.6 million Euros (SENSoR Consortium, 2013). The countermeasure cost includes all the construction costs, the maintenance costs over a 20 year period and/or probable reconstruction costs. All the benefits/costs should reflect the actual local prices, taking into account the economic life of each countermeasure and the discount rate. The outcome of this procedure is the BCR calculation for each countermeasure applied to a specific road section.

The SRIP is conducted for a period of 20 years and shows the list of the most cost effective improvements that are able to reduce the crash risk for all road user types. In that way, the SRIP enables the road authorities to set the priorities properly when developing infrastructure’s maintenance and/or rehabilitation plans.

4. ROAD SAFETY ASSESSMENT OF THE GREEK TEN-T NETWORK

4.1 Death and serious injury in South East Europe and Greece

In the South East Europe region and according to the World Health Organization, the number of road fatalities is more than 11,000 per year. If it is assumed that the ratio of serious/fatal injuries is about 10/1 then there are more than 126,000 fatal and serious injuries annually and the estimated Gross Domestic Product loss due to road traffic crashes is in the region of 2-3%.

In Greece, according to the World Health Organization, the number of road fatalities is about 1,130 per year, the number of serious injuries is about 1,500 and the estimated Gross Domestic Product loss due to road traffic crashes reaches the 2%. The Road Fatalities Rate in Greece is about 12.2 per 100,000 people (WHO, 2013), which is one of the highest in Europe.

Nevertheless, road deaths in Greece were reduced remarkably by 31% between 2010 and 2013 mainly due to the economic crisis which seriously affected traffic volumes and patterns. Road user behavior also improved with less aggressive driving, less speeding and increased use of seat belts and helmets following awareness campaigns, improved enforcement and infrastructure upgrades.

4.2 The inspected Greek network

The inspected road network in Greece is a part of the TEN-T network. It includes 299 sections of total length (road axis) of about 3,600 km. The largest portion of the road is a single carriageway (undivided). The lane width is over 3.25 m, in the length of 85% of the total length of 4,738 km inspected (including undivided sections and both directions of the divided sections). Concerning physical separation between opposing traffic flows and centerline separating trafficts, these are present in 39% of the surveyed network, and concrete safety barrier in 39% as well, while metal median barrier separating traffic lanes by directions is placed in 16%. Paved shoulders are mostly (~47%) 1.0 to 2.4 m wide (medium) on the passenger’s side.

As for the pedestrian facilities, they do not exist on the 99% of the inspected road, i.e. there is a very small number of signalized pedestrian crossings, with or without traffic lights, refuges and grade separated facilities. The same applies for the bicycles as well. Regarding hazardous objects at the side of a driver or passenger in the front seat, such objects are recorded in about 40% of surveyed network. These objects include cliffs, deep canals, steep slopes, trees and poles of a diameter greater than 10 cm, etc. Table 1 below presents some key characteristics of the network inspected:
<table>
<thead>
<tr>
<th>Table 1: Key characteristics of the inspected Greek network</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle flow (AADT)</strong></td>
</tr>
<tr>
<td>&lt;5,000: 17%; 5,000 – 10,000: 15%; 10,000 – 15,000: 19%; 15,000 – 20,000: 5%; 20,000 – 40,000: 9%; &gt;40,000: 6%</td>
</tr>
<tr>
<td><strong>Road type</strong></td>
</tr>
<tr>
<td>Divided carriageway road: 57%; Undivided road: 43%</td>
</tr>
<tr>
<td><strong>Curvature</strong></td>
</tr>
<tr>
<td>Straight or gently curving: 72%; Moderate: 16%; Sharp: 7%; Very sharp: 5%</td>
</tr>
<tr>
<td><strong>Lane width</strong></td>
</tr>
<tr>
<td>Wide (&gt;= 3.25 m): 85%; Medium (&gt;= 2.75 m to &lt; 3.25 m): 11%; Narrow (&gt;= 0 m to &lt; 2.75 m): 4%</td>
</tr>
<tr>
<td><strong>Median type</strong></td>
</tr>
<tr>
<td>Safety barrier - metal: 16%; Safety barrier - concrete: 39%; Physical median width &gt;= 1.0 m to &lt; 5.0 m: 2%; Physical median width &gt;= 0 m to &lt; 1.0 m: 2%; Central hatching (&gt;= 1 m): 2%; Centre line: 39%</td>
</tr>
<tr>
<td><strong>Paved shoulder</strong></td>
</tr>
<tr>
<td>Wide (&gt;= 2.4 m): 8%; Medium (&gt;= 1.0 m to &lt; 2.4 m): 30%; Narrow (&gt;= 0 m to &lt; 1.0 m): 52%; None: 10%</td>
</tr>
<tr>
<td><strong>Speed limit</strong></td>
</tr>
<tr>
<td>&lt;=40 km/h: 4%; 50 km/h: 11%; 60 km/h: 7%; 70 km/h: 8%; 80 km/h: 8%; 90 km/h: 18%; 100 km/h: 8%; 110 km/h: 3%; 120 km/h: 18%; 130 km/h: 15%</td>
</tr>
</tbody>
</table>

4.3 Data used in modeling

**Traffic volume:** Traffic volume data is used in the iRAP model as a multiplier to estimate the number of deaths and serious injuries that could be prevented on the roads. In Greece there is not a single database or source that encompasses traffic volumes of the road network. Traffic volumes are measured only where relevant data is required. Therefore, the necessary traffic volumes of the network under investigation were obtained from the following sources: Ministry of Transport, Infrastructure and Networks, TEN/tec database, Road concession companies (road operators), existing - previous studies of TRANSPORTATION SOLUTIONS Ltd.

**Operating speed:** The level of risk of death or serious injury on a road is highly dependent on the speed at which the traffic travels. The RAP method indicates that risk assessments must be performed using the ‘operating speed’ on a road. Operating speed is defined as being the greater of the legislated speed limit or the measured 85th percentile speed. Estimated operating speeds across the networks surveyed in SENSoR were measured in a series of counts in SENSoR countries (notably in Slovenia) where it was possible to work with road authorities and other stakeholders. When possible, these counts were supplemented with advice from local engineers and police. Informal estimates were also made from the survey vehicle on an ad hoc basis whilst it was travelling as a “floating vehicle” in the traffic stream using techniques long-established in traffic engineering (see, for example, the comments in the “Moving Car Observer” technique (Wardrop and Charlesworth, 1954). Nevertheless, speed data are not usually available for every individual road or section at frequent intervals and, in the absence of detailed information, it is necessary to make assumptions about general speeds over the network based on the available data and local knowledge. Many EuroRAP and iRAP speed surveys have found that it is not uncommon for 85th percentile speeds to exceed the speed limit by 10 km/h over a range of speeds. Within the context and limitations of a drive-through survey, this is the assumption used in this work and generally it is supported by speed counts taken in these countries and their neighbours. When the posted speed limit was at small sections over a long road segment limited to a significantly lesser figure, it was assumed that the operating speeds were remained constant to the overall longer road segment. This was mainly encountered at intersections. It is though recognised that there will be variation between roads and locations, times of day, and indeed between countries, based upon such factors as level of speed limit enforcement, road layout, local features such as bends, general attitudes to speed, levels of traffic, to name just a few. Part of this stakeholder consultation is to seek information and set data collection in place that will provide richer data sources for future road assessments.

**Crash Data:** The crash number, the death person number and the serious injured person number for all roads are used to support the countermeasure selection and economic analysis. The traffic crash data for the years 2010 - 2013 are presented at the following Table.
Countermeasures costs: In order the Safer Road Investment Plan to be developed, the costs of variations on 94 countermeasures must be estimated. This will enable the determination of the benefit-cost ratio of each proposed countermeasure. The costs must include all costs of design, engineering, materials, work, land as well as maintenance for their entire life cycle. Within SENSsOR, these costs were determined using a common pattern based on a research implemented by the SENSsOR project partner AMZS Slovenia. In some cases a low countermeasure cost has been assumed in order to enable the model to consider all suitable candidate sites for that measure.

Analysis period: The number of years over which the economic benefits of the Safer Roads Investment Plan is calculated. The value for this project is set to 20 years.

Gross Domestic Product: The key figure for the Safer Road Investment Plan is the GDP per capita in local currency. As the source of this figure the IMF World Economic Outlook Database of October 2013 was used. The GDP per capita in Greece for 2014 is 16,376 EUR.

Discount rate and minimum attractive rate of return: Discounting is a technique used, among other things, to estimate costs and benefits that occur in different time periods and is used to calculate the Net Present Values (NPV) and budgets required within iRAP’s ViDA software. The appropriate discount rate to use can vary by country and in many investment project modelling exercises is set in consultation with the funder. Typically, the discount rate varies from 4% to 12%, the latter figure being often used in World Bank transport projects. In SENSsOR, a figure of 12% has been used in many countries, whereas in others, after local consultation, 9% and 4% has been used. A sensitivity analysis conducted within the ViDA Model showed that from a practical perspective, at a 12% discount rate compared with 4%, the total Present Value of safety benefits was approximately halved, the overall estimated cost of the investment is reduced by about a third and the estimated number of fatal and serious injuries saved over 20 years is reduced by about 10%. Lists of triggered countermeasures are similar with, as expected, slightly fewer sites or lengths of road recommended for improvement when the discount rate is higher. Again, as part of the consultation process in individual countries, variations on the discount rate can be trialled. In Greece, a discount rate of 9% has been used in this consultation report. The minimum attractive rate of return has been set at the decimal fraction equivalent. High discount rates and the implied zero-traffic growth assumption within the model would mean that the Benefit Cost Ratios and estimates of casualties saved are highly conservative.

Value of life: This figure reflects the social cost of one fatality on the road. According to the Hellenic Association of Transportation Engineers, the value of life is estimated as 1,600,000 EUR.

Value of serious injury: This figure reflects the social cost of one serious injury on the road. In this project the iRAP recommendation of Value of life x 0.25 (see McMahon and Dahdah (2008)) was used. Thus, the value of serious was estimated as 400,000 EUR.

4.4 The Star-Rating results

The star rating is based on individual relative risk for three user groups – vehicle occupants, passengers and motorcyclists. Bicyclists’ results were excluded because of lack of bicycle usage (they represent less than 0.01% in rural roads). Therefore, three different star ratings were produced. The Star Ratings results for the entire road network analyzed are presented in the next Table for each user group.
As seen on the above table, less than 0.5% of the Greek surveyed network was awarded 5 stars, and only 4% was awarded 4 stars for the vehicle occupants. 45% of the network was awarded 3 stars, while more than one-third (35%) of the network gained only one star. The rating for the motorcyclists is worse when the majority of the network belongs to the one-star high-risk category.

Pedestrians’ results are distorted by the fact that more than half of the inspected network was not star rated for pedestrians. This is due to non-existent pedestrian flow on these sections. The examined roads are dual-carriageway, rural highways. Nevertheless, it is evident that the rated road sections for the vulnerable road users were awarded poor rating, especially the pedestrians’ safety rating turned out to be very low. The total length adds up to 4,738 km which is more than the network length stated (3,600 km). This is due to the fact that the dual carriageway roads were surveyed in both directions.

3.5 Safer Roads Investments Plan (SRIP)

The SRIP for the entire surveyed network would save 26,520 fatalities and serious injuries over the analysis period of 20 years. The cost of these countermeasures adds up to approx. 1 billion EUR. The total BCR of the entire investment plan is 6. The next Figure presents the top 10 countermeasures of the SRIP in terms of saved lives and serious injuries (FSI). In addition to the measures presented here, it is likely that benefits would result from the upgrading of the 107 (75%) pedestrian crossings described as of poor quality.
It is clear that the SRIP would improve the Greek road network safety significantly. For vehicle occupants, the number of 1-Star high-risk roads would decrease to only 3%, whereas the 5-Star roads would be present in 15% of cases. Overall number of 91% of 3-or-more-Star roads is undoubtedly a good result. There are improvements in the motorcyclists’ and pedestrians’ safety as well. However, effect of the SRIP on these user groups is relatively lower than for the vehicle occupants.

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PAPER TITLE
GEOGRAPHIC INFORMATION SYSTEM FOR INTERSECTION TRAFFIC CONFLICT ASSESSMENT IN EAST TEGAL SUBDISTRICT, INDONESIA

TRACK
SAFER ROADS

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KEYWORDS:
Intersection conflict, Conflict assessment, Database, WebGIS

ABSTRACT:
Traffic conflict at intersection varied because each intersection have different characteristics. Traffic conflict potential can cause an accident (Baguley, 1984). An assessment are needed to reduce traffic conflict. The first step is to do safety inspection at the intersection to know that causes of conflict or potential danger, so can be determined an appropriate assessment to reduce the conflict. Safety Inspection at the intersection conducted with the priority assessment by level of conflict seriousness, which on road geometry, road complementary building and road facilities while the level of conflict seriousness determined by the Traffic Conflict Technique Method (Hyden, 1987). Once the cause of the conflict known then performed the intersection safety engineering by considering benefit/cost ratio and the reduction factor, which results in a safety recommendation. Based on analysis at 23 intersections in East Tegal Subdistrict found 4 intersections have high conflict seriousness and need priority assessment, with most high conflict seriousness at Pertamina intersection. Then decide an assessment by rumble strip installation which have 30% collision reduction and benefit/cost ratio by 26.49. In transportation problems, especially the road safety problem in Indonesia is carried out by several agencies that has each function (Constitution Number 22 of 2009), so we need a system that can accommodate the needs of coordination of the agencies, especially in terms of data requirements, namely the creation of a Geographic Information System For Intersection Traffic Conflict Assessment with a database and presented in WebGIS.
Geographic Information System for Intersection Traffic Conflict Assessment in East Tegal Subdistrict, Indonesia

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1. INTRODUCTION

The intersection is a node on the traffic network where the streets meet and intersect the vehicle trajectory. Intersection is a place where the flow of traffic moving in different directions and come together. At the intersection of a conflict of traffic that could potentially cause an accident. In an effort to improve intersection safety there are two strategies, accident reduction strategy and accident prevention strategy. Accident reduction strategy based on the number of accidents cases, therefore this strategy relies heavily on accident data which is not easy to obtain them. while accident prevention strategy is not based on the cases of accident or accident data, because they are prevention (pro-active). Traffic conflict assessment is a prevention strategy in efforts to increase safety at intersections. Due to evaluate an intersection can be seen from the traffic conflict that occur without waiting for accident data from the police (Santoso, 1990).

Conflict assessment steps include identification, assessment selection techniques, and data analysis. Assessment selection techniques considering the category of conflicts in accordance with the results of the data analysis, characteristics of the intersection, and costs. There is different authorities in Indonesian transport, as is the authority of Ministry of Public Work in road construction, road facilities and equipment is the official authority of Ministry of Transportation, and the accident investigation authority is the National Police. Therefore we need a system that can accommodate the needs of the necessary data and facilitate the acquisition of intersection information. The system should be able to support stakeholder decision to choose the type of treatment. So in the system, previously determined the relationship between the factors considered in the selection of the type of treatment. WebGIS that used can be determined users and allows the presentation of data that is relevant, accurate, timely, economical, efficient, reliable, and consistent.

2. LITERATURE REVIEW

Traffic Conflict

Traffic conflict is a situation in which one or more of the road users approach each other or close to other objects in space and time in such a way that a risk of collision if the movement can not be changed. (CJ. Baguley, 1984) Data conflict studies to help identify the problems most likely to be an accident at an intersection. Such data can be used to evaluate the road without having to wait for the crash data.
Intersect motion control movement (Crossing) is more dangerous than weaving, and subsequently, more dangerous than the motion over the join (Merging) and split (Diverging) due to the relative velocity includes him great speed. (Yansor, 2012).

**Accident Reduction Factor**

Accident reduction factor is the percentage of accidents which are expected to decline after applying to the countermeasure of certain roads. This reduction factor must be considered as a general estimate. Reduction factor should consider the technical assessment, the environment, traffic volume, traffic composition and road geometry that affect in safety. If using more than one countermeasure the proposed use of the largest value of the reduction factor. Accident factor in this research compiled from technical guideline 1 Road Safety Engineering Binamarga 2012.

**Web GIS (Geographical Information System)**

GIS is a computer-based system (CBIS) that used to store and manipulate geographic information. GIS is designed to collect, store, and analyze object and phenomena. Geographic location is an important characteristic or critical to be analyzed. GIS is a computer system which has the following four capabilities in handling geographically referenced data. i.e. inputs, data management (storage and retrieval), analysis and manipulation of data, and output (Aronoff, 1989) In the development of WebGIS, the flow of information process has an important role. Process flow is a vehicle for the provision of information to understand how the process of request for information by the visitor, then managed by the server, and then the information is presented in the map. Figure explain about Information Provision Process Flow.
3. METHODOLOGY

Research methodology explains how the phase of this research. The research is a quantitative research by compare the condition of the intersection before and after countermeasure.

a. Literature review

Describe the problems existing conflict with the theories that have been described by previous researchers. Study of literature useful to know for certain theories that became the basis for the research and measures used in achieving the goals of the research.

b. Data collecting (conflict data before countermeasure)

At this step done two types of survey to find out the problems at the intersection, which conducted a survey of conflict at the intersection with high safety problems with the Traffic Conflict Technique (TCT) method. This survey is useful to know the type of conflict and the seriousness of the conflict in the intersection.

The next survey is a survey of the characteristics of the intersection. Survey is a survey conducted road safety inspection and survey performance intersection. Road safety inspection surveys useful to know the factors that can lead to intersection safety deficiencies.

c. Conflict Categorization

Research evaluated the seriousness of the conflict with the Likert scale (with 1 representing the lowest level of seriousness to 4 representing the highest seriousness) for quality and accuracy. The seriousness of the conflict known by TCT method. Based on these two Likert scale code used in determining the seriousness of the conflict is the first code to a serious conflict with the type of movement crossing, code 2 for a serious conflict with the type of movement other than the crossing, code 3 for non-serious conflict with the type of crossing movements and code 4 for non serious conflict with the type of movement other than the crossing.

The total value of the seriousness of the conflict (N) obtained by the sum score of the conflict seriousness for 1 hour during rush hour. The seriousness of the conflict are grouped into three categories, namely the group of high, medium and low. The third division of categories is seen from the total value of the seriousness of the conflict (N). As for qualifying third grouping these categories using statistical means. Grouping by way of statistics done by calculating the average - average value of the total seriousness of the conflict (N) and standard deviation. The formula for finding the average (mean) as follows:

\[
\text{Mean} = \frac{\sum X}{N} \tag{1}
\]

Annotation:
\(\Sigma X\) : Total Score
N : Number of conflict

The formula to find the standard deviation is:

\[
SD = \sqrt{\frac{\Sigma X^2}{N} - \left(\frac{\Sigma X}{N}\right)^2} \tag{2}
\]

SD: Standard Deviation
(\(\Sigma X^2\) / N: Each score is squared and then added together and then divided by N
(\(\Sigma X\) / N: All the scores were added up, then divided by N squared

After calculation, obtained a mean value of 164 and a standard deviation value of 82. The results of the determination of the grouping of the total value of the seriousness of the conflict showed to be classified into high value of the seriousness of the conflict should have a value of 246. Values above the seriousness of the conflict is classified into the low group must have a value under 82 and the rest are between grades 82 through 246 are included in the medium value of the seriousness of the conflict.

d. Countermeasure Assessment

After analysis of the causes of conflict in the previous step it will be assessment the problems with accident reduction factor, Intersection characteristic and countermeasure cost. Researchers chose confectionary accordance with the conditions and causes of conflict junction at the intersection. This countermeasure is the core in this study because it will determine the outcome of conflict reduction.

e. Countermeasure analysis

The process of analysis on this trendline analysis phase consists makes graphs then added with various types including logarithmic trendline, exponential, linear, polynomial, and power so that in getting the highest R² value of the five types. R² is the highest value that is then used for subsequent
analysis. The next analysis is to calculate the value of Y at the highest $R^2$ so on get the forecast value. Countermeasure analyse is make the consideration about accident prevention.

f. Relationship equation between Accident reduction factor, assessment and cost

From the analysis of impact assessment, intersection characteristic and showed figures that will be used to find the relationship between the three variables. The relationship between these three variables obtained from the equation emerging from the analysis graph showing pliting of each variable. Of the line formed knowable relationships between variables by classifying the level of conflict.

g. Data Presentation

After treatment, we need a database for storing and documenting the results of the survey and the handling is done. Therefore established a geographic information system which is the intersection of conflict of data center conditions and handling of the intersection.

Of a roll, the above step are performed on the scene can be made as follows:

![Flowchart of methodology](image)

**Figure 3. Research methodology**
4. RESEARCH RESULT

Based on analyse from conflict data in intersection with conflict categorization then can be obtained data in table 1.

Table 1. conflicts and categories

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Serious conflict (Peak Hour)</th>
<th>Non serious conflict (peak hour)</th>
<th>N total with likert scale</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hanoman</td>
<td>Cross 15</td>
<td>Diverging 6</td>
<td>Merging 11</td>
<td>Weaving 9</td>
</tr>
<tr>
<td>UPS</td>
<td>33</td>
<td>13</td>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td>Langon</td>
<td>36</td>
<td>9</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>Durian</td>
<td>14</td>
<td>4</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>Pramesti</td>
<td>19</td>
<td>6</td>
<td>18</td>
<td>7</td>
</tr>
<tr>
<td>Polres</td>
<td>25</td>
<td>9</td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td>Gili Tugel</td>
<td>11</td>
<td>5</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Pertamina</td>
<td>61</td>
<td>8</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Martoloyo</td>
<td>25</td>
<td>14</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>Panggung Baru</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Surabaya</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Sipayung</td>
<td>11</td>
<td>6</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Mangkukusuman</td>
<td>9</td>
<td>3</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Mejabung</td>
<td>6</td>
<td>2</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Diponegoro</td>
<td>14</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Kejambon</td>
<td>11</td>
<td>4</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Mintaragen</td>
<td>15</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Nias</td>
<td>18</td>
<td>5</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Sumbodro</td>
<td>15</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Serayu</td>
<td>13</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Citarum</td>
<td>14</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Cikditiro</td>
<td>13</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Sukrosono</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Compiled from data analyse 2012

Of the 23 studied intersection turns out there are 4 intersections with values in the category of high seriousness conflict, it is the UPS intersection, Langon intersection, Pertamina intersection and Martoloyo intersection. There are three intersections with values in the category of Low seriousness conflict, namely the Surabaya intersection, Mejabung intersection and Sukrosono intersection, and the rest fall into the category of Medium. Conflict at the intersection and then selected by considering a handling characteristics, impact assessment and cost required. Types of treatment and costs can be seen in the table below:

Table 2. Conflict assessment

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Category</th>
<th>Countermeasure</th>
<th>Reduction Factor (%)</th>
<th>Cost (Rp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hanoman</td>
<td>Medium</td>
<td>Signalized intersection</td>
<td>45</td>
<td>214,850,155</td>
</tr>
<tr>
<td>UPS</td>
<td>High</td>
<td>Increase traffic sign</td>
<td>30</td>
<td>19,508,550</td>
</tr>
<tr>
<td>Langon</td>
<td>High</td>
<td>Improve visibility</td>
<td>50</td>
<td>20,450,000</td>
</tr>
<tr>
<td>Durian</td>
<td>Medium</td>
<td>Line marking to describe this type of arrangement intersection</td>
<td>10</td>
<td>7,589,800</td>
</tr>
<tr>
<td>Pramesti</td>
<td>Medium</td>
<td>Rumble strip on approach</td>
<td>30</td>
<td>24,765,000</td>
</tr>
<tr>
<td>Polres</td>
<td>Medium</td>
<td>Increase traffic sign</td>
<td>30</td>
<td>5,951,472</td>
</tr>
<tr>
<td>Gili Tugel</td>
<td>Medium</td>
<td>Signalized intersection</td>
<td>45</td>
<td>214,850,155</td>
</tr>
<tr>
<td>Location</td>
<td>Category</td>
<td>Action</td>
<td>Cost (Rp)</td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>----------</td>
<td>---------------------------------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>Pertamina</td>
<td>High</td>
<td>New Roundabout</td>
<td>85</td>
<td>89,730,050</td>
</tr>
<tr>
<td>Martoloyo</td>
<td>High</td>
<td>Increase traffic sign</td>
<td>30</td>
<td>19,508,550</td>
</tr>
<tr>
<td>Panggung Baru</td>
<td>Medium</td>
<td>Changing into a stop sign</td>
<td>5</td>
<td>1,487,868</td>
</tr>
<tr>
<td>Surabayan</td>
<td>Low</td>
<td>Traffic island and marking</td>
<td>45</td>
<td>27,654,025</td>
</tr>
<tr>
<td>Sipayung</td>
<td>Medium</td>
<td>Make a median</td>
<td>60</td>
<td>15,970,000</td>
</tr>
<tr>
<td>Mangkukusuman</td>
<td>Medium</td>
<td>Make traffic island or median in rural</td>
<td>45</td>
<td>21,090,780</td>
</tr>
<tr>
<td>Mejabung</td>
<td>Low</td>
<td>Increase traffic sign</td>
<td>30</td>
<td>19,508,550</td>
</tr>
<tr>
<td>Diponegoro</td>
<td>Medium</td>
<td>Signalized intersection</td>
<td>45</td>
<td>185,460,495</td>
</tr>
<tr>
<td>Kejambon</td>
<td>Medium</td>
<td>Signalized intersection modification</td>
<td>55</td>
<td>12,850,000</td>
</tr>
<tr>
<td>Mintaragen</td>
<td>Medium</td>
<td>Changing into u-turn</td>
<td>62</td>
<td>60,325,550</td>
</tr>
<tr>
<td>Nias</td>
<td>Medium</td>
<td>Improve visibility</td>
<td>25</td>
<td>5,418,966</td>
</tr>
<tr>
<td>Sumbodro</td>
<td>Medium</td>
<td>Rumble strip on approach</td>
<td>30</td>
<td>24,765,000</td>
</tr>
<tr>
<td>Serayu</td>
<td>Medium</td>
<td>Stop sign installation</td>
<td>20</td>
<td>6,091,720</td>
</tr>
<tr>
<td>Citarum</td>
<td>Medium</td>
<td>Stop sign installation and marking</td>
<td>35</td>
<td>6,091,720</td>
</tr>
<tr>
<td>Cikditiro</td>
<td>Medium</td>
<td>Improve visibility</td>
<td>50</td>
<td>20,450,000</td>
</tr>
<tr>
<td>Sukrosano</td>
<td>Low</td>
<td>Stop sign installation and marking</td>
<td>35</td>
<td>6,091,720</td>
</tr>
</tbody>
</table>

* Contermeasure and reduction factor compiled from technical guideline 1 Road Safety Engineering Binamarga 2012
** Cost compiled from cost standard ministry of transportation 2014

Reduction factor is used as an impact assessment for later sought a model relationship with the intersection characteristics and cost required in countermeasure. So it can be used as a consideration in the decision to stakeholder would apply if the treatment field. Application of webGIS is to address issues related to the authority in handling the implementation in Indonesia not only by one stakeholder.

Relation Model

![Figure 4. Relation model between Intersection characteristic, Impact Assessment, and cost graphic](image)

The most high $R^2$ value or the closest one, the data on the intersection with the category of seriousness Low level is linear type that has a $R^2 = 0.294$ and has the equation $y = 8E + 07x - 1E + 07$. Medium seriousness level category is the type of power that has $R^2 = 0.418$ and has the equation $y = 1E + 08x^{1.382}$. $R^2$ value of each category of High and Medium are relatively small numbers, the condition is due to the amount of sample data which has categories intersection of High and Low extremely small. While the Medium category got the model or type of trendline, with the most high $R^2$ value or the most close to 1, the data on the intersection with the seriousness of the Medium category is the type of Exponential who have $R^2$
= 0.887 and has the equation \( y = 8 \times 10^6 e^{2.743x} \). 0887 R² value is a number of the most high compared to the type - another type.

WebGIS for Intersection Traffic Conflict Assessment

![WebGIS for Intersection Traffic Conflict Assessment](image)

WebGIS easily to access for people in all gadget because it web based technology. webGIS above include some additional enable this feature, such as a login form for each stakeholder with username and password protection, discussion forum if there is something that needs to be discussed related to the handling of the intersection, stakeholder can provide feedback or comments on the form of these discussions, the location of the intersection itself right on the coordinates of each intersection, list of Benefit Cost Ratio that can calculated automatically comparation between benefit and cost of the countermeasure that choosen by stakeholder, as well as the most important contained intersection relation between characteristic models, Impact Assessment, and cost that comes with photos and countermeasure simulation.

5. CONCLUSIONS

From the analysis of relationship between intersection characteristic, impact assessment, and cost can conclude that equation for low seriousness conflict is \( y = 8 \times 10^7 - 1 \times 10^7 \), for medium seriousness conflict is \( y = 1 \times 10^8 x^{1.382} \), and for high seriousness conflict is \( y = 8 \times 10^6 e^{2.743x} \). 0887. But for R² value from high and medium conflict are relative small number so that required farther research with larger scale and a larger number of samples to obtain more valid data. with this equation we can determine the relationship between intersection characteristic, impact assessment, and cost. and case analysis if stakeholder who want to know the value one of the three variable from the conflict assessment. And with the webGIS, and of the method set forth in WebGIS, can make it easier for stakeholders to decide the type of countermeasure.

6. REFERENCES


RAINVISION: Influence of the performance of road markings in driver behaviour – Wet night Visibility (22 June 2015)

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ABSTRACT

Previous research (e.g. COST 331 - Requirements for Horizontal Road Marking) and studies (Improve - Harmonisation of road signs and road markings on the TERN from a safety point of view) have confirmed that the night visibility of road markings is an essential contributor to driver comfort and road safety. Nevertheless road markings are generally neglected, in many cases have even completely disappeared.

At the same time, as current demographic trends continue, 1/3 of drivers will be above 60 years old by 2020. Road accident statistics indicate that older drivers are more likely to be involved in accidents than their younger counterparts.

In this context, and capitalising on previous projects, RainVision, aims to study the influence of road marking on driver behaviour, by mainly analysing how different age groups (young vs middle vs old) and different gender groups (male vs female) adapt their driving behaviour on the basis of the visibility and retroreflectivity of road markings under all weather conditions, (i.e. dry, wet, wet and rainy) during night time driving. The final test results will be transposed into a series of recommendations that will be widely distributed to stakeholders involved in road safety.

KEYWORDS: road markings, driver behaviour
1. **INTRODUCTION**

COST 331, which ran from 1996 to 1999, mainly focused on dry night conditions and indicated that the increased luminance of road markings, resulting in a better delineation of the road, contributes to an increased comfort by offering more reaction time to the drivers. On average a slight increase in speed was noted, but the increased visibility was mainly converted into more reaction time.

IMPROVER, which ran from 2004 to 2006, concluded that road markings are a key factor to achieve safe road infrastructure. Nevertheless, road markings are generally neglected and, in many cases, have even completely disappeared. Several recommendations were provided for high accident areas and the project confirmed the need for ‘wet-night visibility’

The project continues where COST331 stopped and studies the influence of road markings on night time driver behaviour by examining the following aspects:

- Does better visibility of pavement markings during wet and rainy nights contribute to better driving comfort and road safety?
- How does the impact of increased visibility vary according to age?
- Other things being equal, do men and women show different reactions?

The addition to the two aforementioned European studies, the project will also perform an in-depth review of state of the art of road markings research in EU Member States and non-EU states (USA etc.).

The road markings used will be tested according to the European Norm (EN) 1436 Road marking materials — Road marking - performance for road users. This norm defines the various performance classes, levels and test methods for ‘Dry’, ‘Wet’ and ‘Rain’ night time retro-reflectivity as well as colour, daytime luminance and skid resistance.

The findings of the trials will feed into a series of recommendations that hopefully will provide valuable insights on how road markings impact human behaviour and how road markings can be optimally applied to maximise comfort levels and ultimately safety on Europe’s roads.

2. **THE RAINVISION APPROACH**

RAINVISION will deploy an innovative three level approach that will involve:

- **A simulation phase** which will entail the use of computer simulation technology, to perform a series of tests to study driver behaviour in relationship to different road conditions that will facilitate the determination of the performance levels of the materials used for the track test.

- **A track test phase** whereby, on the basis of the findings of the simulation studies, volunteer drivers will perform runs on track tests that will be designed to correspond to different scenarios.

- **An on road test**, which will entail the application of different types of road markings materials on rural roads in the United Kingdom and monitor their impact on driver behaviour over a specific time frame.
2.1. Simulation Test

The simulation will allow the project to better determine the suitable thresholds of retro-reflectivity where a reasonable impact on human behaviour can be observed. This will facilitate the determination of the performance levels of the materials used for the track test.

2.1.1 Simulation Test Design

This simulation test will take into account several parameters:

- Different driving conditions: day/night weather dry/wet/wet and rainy
- Road marking performance: level of visibility
- Road Geometry: straight and curved sections
- Age and gender

The simulation will involve 90 drivers. Three age groups are analysed: 20-40, 41-60 and 61+ years old drivers, both male and female.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>20-40 years</th>
<th>41-60 years</th>
<th>61 years and over</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Female</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

TABLE 1 Composition of Drivers

To be able to interpret results, test subjects will be specifically evaluated by means of visual abilities tests (close, medium and far vision, perception of contrast in photopic and mesopic conditions) in order to provide homogenous test groups.

2.1.2 Simulated Driving Environment

The drive test will use only one type of vehicles, i.e. passenger car. The reference driving scenarios will involve a 5 km road, each scenario reproducing specific driving conditions for a given level of visibility. The duration of the full test is approx. 30 min session including visual abilities evaluation and driving
sessions for the handling/learning of the simulator and for the tested conditions, with 5 to 6 min drive per scenario (average speed approx. 60 km/h i.e. 1 km per min).

The road markings geometry (width, length, modulation of broken lines including gaps, position on the road) will be based on the French regulation, given the sample of subjects.

Concerning traffic conditions, as crossing vehicles headlamps can trouble the driver’s vision; the scenarios will include a low rural traffic (cars and some trucks).

Compilation of the individual data and subsequent analysis will involve analysing:

- The effect of different levels of road markings visibility on speed and trajectory of users by night under wet and rain conditions (measured indicators)
- The effect of different levels of road markings visibility on the declared perception of the road by the subjects tested on simulator (satisfaction, confidence)
- The determination of the performance levels of the materials used for the track test and the on-site test

![FIGURE 1 Picture of Simulator.](image)

2.2 Track Test

A series of off-road tests were conducted in Austria in order to assess the impact of road markings on driver behaviour, simultaneously to the aforementioned simulation study.

2.2.1 Experimental design of the track test

Participants will drove on a test track, containing several typical road characteristics, like left and right bends or a straight road. Drivers’ performance was investigated in three test conditions:
1. Condition I: Baseline, no or existing (non-reflective) lane marking
2. Condition II: Site equipped with marking material I (wet night visibility performance product)
3. Condition III: Site equipped with marking material II (enhanced wet night visibility performance product)

Drivers took several runs through specifically chosen road sections, completing the track in 3 different night time driving situations: dry, wet and wet & rainy.

To ensure comparability with the results of the simulation studies, the sample of drivers respected the same group categorisation.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>20-40 years</th>
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</tr>
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<tr>
<td>Female</td>
<td>15</td>
<td>15</td>
<td>15</td>
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</tbody>
</table>

**2.2.2 Driver comfort measurement**

To determine the extent to which the different types of road markings have an impact on the driver, the test track focused on driver comfort. This was measured by the behaviour (lateral and longitudinal g-forces), speed choice and subjective stress levels (by using a questionnaire) of drivers.

The drives were recorded with specifically instrumented vehicles, equipped with a tool which allows all relevant variables to be captured. Additionally, perceptual skills were tested in order to ensure homogenous test groups. Skills like reactivity, peripheral perception, tachystoscopic and visual structuring abilities are tested.

This was done using the p-drive system. It is a video and data recording system which can be mounted easily in any vehicle. Whilst driving, all important data of the vehicle and the driver are recorded. Therefore, a GPS-antenna, two video cameras and a G-force sensor register all movements of the vehicle and the driver in an objective and fraud resistant way. Additional to the driving speed, longitudinal forces (acceleration, deceleration) and lateral forces (steering maneuvers) are measured. Furthermore, the system records date, time, video and audio data simultaneously and stores all data on a compact flash card.
2.2.3 Description of the Track

The track test was carried out near the Austrian city of Melk, i.e. the “Wachauing”. This closed circuit is situated in lower Austria and is about 12Ha in size.

For the RAINVISION project, a track route (approx. 1000m) was selected in a way that potential differences of marking levels could be identified by means of driving data (speed, lateral and longitudinal acceleration). Due to an economic test design, test subjects completed the track in one driving direction (clockwise).
Test drives were carried out within three different marking conditions (non-reflective=baseline, marking material I=reflective material, marking material II=wet reflective material) under three different driving conditions: (dry, wet and wet & rainy). For testing condition II and III, the whole track was moistened by sprinkler irrigation.

First results from the track test indicate that driving comfort was assessed best when marking material II (wet-reflective) was applied on the track.

Regarding driving behavior by means of speed choice, (measured as lap times), test subjects drove slowest in the baseline condition, faster under condition with applied marking material I (dry reflective, type I), and slightly faster under condition with applied marking material II (wet reflective, type II). The higher speed should not be generally associated with a reduction in traffic safety.

2.3 On Road Trials

The simulation study and the track test will be complemented by an on road study that is currently being conducted in the UK.

Ten trial locations have been identified. Following the collection of baseline speed data road marking materials with different levels of wet night performance have been installed. Accident and driver speed data is currently being collected over a full climatic cycle, following which a detailed analysis will be undertaken in order to evaluate the impact of the enhanced markings on accident levels and driver behaviour in terms of speeding.

A driver interaction campaign is currently being developed within each highway authority area to evaluate a range of responses from drivers in relation to the impact of the markings. This campaign shall
involve both social media and local radio stations to collect driver feedback and whilst not truly objective will result in the collation of indicative responses from drivers to the installation of high performance road markings and the subsequent impact on variables such as driver speed and comfort.

Practically, the on-road trials involve the following stages of implementation:

Stage 1: Site identification and initial data collection

i) Identification of high risk sites suitable for application of high performance materials
ii) Initial data collation of accident statistics over previous 12 month period.
iii) Establishment of baseline driver speed data on all selected sites with up to 6 weeks data collected on each site.

Stage 2: On Road Test

i) Installation of high performance wet night visibility products to all identified sites
ii) Discrete monitoring of driver speed on each site over the duration of the climatic cycle (10 mobile cameras for 20 sites)
iii) Collation of accident statistics for period of one climatic cycle following initial installation
iv) Driver interaction programme via internet and regional radio

Stage 3: Detailed statistical analysis of speed and accident data

i) Analysis of available speed data per site and across all sites
ii) Analysis of available accident data per site and across all sites
iii) Preparation and submission of On Road Test report

2.4 Handbook of Recommendations

Based on the findings from the simulation, the track and on-road tests, the WP will consist of analysing the date obtained and drawing conclusion concerning the impact of road marking on driver behaviour. More specifically, the analysis will focus on the inter-correlation of different factors, i.e. the age and sex of drivers, visibility levels of road marking and weather conditions (dry vs. wet). The conclusions will feed in a recommendations handbook that will be made available to road authorities and stakeholders involved in road safety. The recommendation will adopt a forward looking attitude that will aim to capture how road marking applications will have to change in order to meet the needs of an ageing driver population.

The handbook will be presented in the project’s final conference in Brussels.
3. CONCLUSIONS

For the simulation and test track trials, the results clearly show that the application of reflective marking material has a positive effect on the subjective comfort feeling of drivers, especially in adverse driving conditions which were simulated in this experiment. Under night-time and rainy driving conditions, the wet retro-reflective material was assessed as clearly guiding the driving path, thus providing anticipatory stimuli of road environment and taking mental workload off the driver.

For the on-road trials, an analysis of accidents before and after the application of wet retro-reflective material actually showed an increase in accidents, i.e. 21 compared to 14. At the same time, the increase in recorded road vehicle incidents identified during the investigation period, could not be directly associated to causes relating to performance of road markings. Interestingly, results indicated that enhanced retro-reflective road markings installed for this stage of the project did not lead to higher vehicle speeds, as potentially anticipated. On the contrary, speed decreases of about 2mph on average across all sites were observed when controlled for weather conditions.

From a traffic safety perspective, the main difference in terms of traffic safety lies in the question whether to apply or not to apply reflective marking material at all. If reflective material is applied, the better choice is to use wet reflective material instead of non-reflective material as the benefits (subjective driver comfort and better anticipation of road trajectory) outweigh the disadvantages (slightly higher speed choice) for drivers.
ACKNOWLEDGEMENTS

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[2] IMPROVER - Subproject 4: Harmonisation of road signs and road markings on the TERN from a safety point of view

Establishing a safety management system for the non-urban road network -
models developed and future needs

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KEYWORDS:
Safety management system, non-urban roads, safety performance functions, hazardous locations

ABSTRACT:
The National Transport Infrastructure Company (NTIC) is in charge of the construction and maintenance of non-urban roads, in Israel. The NTIC stated its goal as providing for continuously improved safety levels of the road network. To support the implementation of this policy, a safety management system (SMS) was established. The main functions of the SMS lie in dealing with the identification of hazardous locations (HL) on existing roads, accumulating knowledge on road safety treatments, providing data and tools for conducting network analyses and monitoring road infrastructure improvements. The main system components include: databases on road characteristics, traffic volumes and road accidents, including video-log data collected by road surveys and a GIS-platform for data presentation; safety models; and supportive tools for monitoring safety improvements in a single project, for conducting analyses of the safety performance of the road network and for producing summary reports.

The SMS safety models include safety performance functions (SPF) and a procedure, which were developed for the HL identification on the existing road network. The HL are defined as locations where the number of accidents is higher than would be expected according to their characteristics and, thus, could be treated for improvement. In line with the state-of-the art in road safety, the HL identification is based on an empirical Bayes evaluation, where the number of accidents expected at a site is estimated as a weighted value considering both the number of accidents that occurred at the site in the past and the number of accidents predicted for similar sites using an SPF. An HL is recognized using a high positive difference between the number of accidents expected at the site and that predicted for similar sites. Identifying the sites with irregularly high accident numbers, this approach enables us to exclude the impacts of such confounding factors as exposure, infrastructure characteristics, and regression-to-the mean. The SPF is a multivariate model predicting the annual accident number at a site based on its traffic volumes and road infrastructure characteristics. For the local conditions, SPFs were developed for single- and dual-carriageway road sections, and for various types of intersections: signalized/un-signalized, three- and four-legged. In addition, both the models and the HL identification procedure account for various accident severities (slight, serious, fatal) which have obvious economic implications both on selecting HL sites and justification of their treatments.

The procedure of HL identification is applied annually, serving as a basis for the NTIC working program on road infrastructure improvements. Positive safety effects of such improvements were recently reported in a local study. These activities comply with the Road Infrastructure Safety Directive that was recently introduced in the EU.

In the future, due to physical changes made in the network and the general decreasing accident trends observed, a recalibration of the SPFs is needed. The issues of dynamic segmentation of the road network and accounting for accident under-reporting should be explored as well. In addition, a wider implementation of pro-active methods for recognizing potentially hazardous sites should be considered.
Establishing a safety management system for the non-urban road network - models developed and future needs

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1 INTRODUCTION

The National Transport Infrastructure Company (NTIC) in Israel is responsible for maintenance, upgrading and expansion of the rural (non-urban) road network, which currently comprises over 4,500 km of roads. In 2007, the NTIC initiated establishing a decision-support system for managing the road system under its responsibility - a Maintenance Management System, which unites three systems: a pavement management system, a bridge management system and a safety management system (SMS). The NTIC stated its goal as providing for continuously improved safety levels of the road network. The SMS is intended to support the implementation of this policy. In a broad vision, the SMS should assist in two processes: (a) treatment of hazardous locations on the existing road network, and (b) upgrading the safety of the road system. Therefore, the main functions of the SMS lie in dealing with the identification of hazardous locations (HL) on existing roads, gaining information and knowledge on road safety treatments - infrastructure improvements for removal/reduction of safety risks, providing data and tools for conducting network analyses and monitoring road infrastructure improvements (SMS 2007). In addition, the SMS may assist in economic evaluation and planning investments in road infrastructure improvements.

Figure 1 presents an initial functional specification of the system (according to SMS 2007), with a database, tools and a knowledge-base planned. Currently, the main SMS components include: (a) databases, (b) safety models and (c) supportive tools for monitoring safety improvements in a single project, for conducting analyses of the safety performance of the road network and for producing summary reports. In line with the initial specification, the SMS databases consist of:

* Road surveys - information on road infrastructure characteristics collected through periodic field surveys of the whole road network, including geometric characteristics, roadside conditions, signing and marking, presence of safety devices, etc. The information is available in the form of both detailed video-log data and quantitative values estimated for road units;
* Road accidents - numbers and characteristics of accidents produced from the annual road accidents files of the Central Bureau of Statistics (CBS);
* Traffic volumes - average annual traffic volumes on road sections and intersections, from the CBS traffic count files;
* GIS - a geographical information system (GIS) platform for data presentation;
* A knowledge-base about road infrastructure improvements including descriptions and values regarding their safety efficiency. The latter are given in terms of safety effects or accident modification factors stemming from both local studies (e.g. Gitelman et al. 2014) and international experience (e.g. Elvik et al. 2009).

Presently, the SMS includes two types of models: (1) Reactive models (or safety models) which are used for identification of hazardous locations on existing road network, and (2) Pro-active models which may help in detecting sites with infrastructure deficiencies that increase accident risks. The reactive models fit the original module B (see Fig.1) and are applied regularly, providing a basis for building the programs of road infrastructure improvements. The pro-active models refer to the planned module A, but are still rarely used.

The SMS safety models include safety performance functions (SPF) and a procedure, which were developed for the HL identification on the existing road network. A safety performance function is a multivariate model, which shows a relationship between accidents and traffic flows and (optionally) other road characteristics of the road sites (Hauer 1997; Persaud 2001; Elvik et al. 2009) and, thus, can be used for predicting the annual accident number at a site based on its traffic volumes and road infrastructure characteristics. SPF models are usually developed for certain types of road sites, where according to the international practice of correct safety evaluations (PIARC 2003; HSM 2010), they should be applied for estimating the expected number of accidents at a site, prior to the HL selection. In this paper, we will
describe a procedure that serves for the HL identification on the rural road network, in Israel, and present SPF that were developed for various types of sites under the local conditions. Furthermore, future needs of the SMS are discussed, considering recent changes in the safety level of the local road network and international developments.

2 THE HL IDENTIFICATION PROCEDURE

Improving the safety of the road network is not based on rebuilding the entire network, but on improving parts of it. The concept of HL identification assumes that there are road sites - road sections and intersections, with engineering deficiencies, which do not function properly from a safety viewpoint. The exposure level at such sites, as reflected in the traffic volumes, does not explain the high accident numbers observed. Therefore, there is probably a design deficiency or inadequacy of road characteristics compared to the requirements that can be identified and improved.

The process of HL identification is intended for an initial screening of road sites, in order to focus on sites more “promising” in terms of potential benefits of intervention - the application of road engineering measures (Hauer 1996; PIARC 2003). This process can be described as an examination of accident frequencies on road sites of the network, in order to point out the sites with "irregularly high" accident numbers (PIARC 2003). The threshold value for such an examination (or "normal" accident numbers) is defined by a reference population (RP). The difference in safety between the site and the RP indicates the extent of the problem of a particular site or its potential for improvement. In a general case, not a simple difference between accident numbers, but a difference between the quantitative criteria is estimated as:

\[ PI_j = IC_j - IC_{RP} \]  

where \( PI_j \) – potential for improvement at site \( j \); \( IC_j \) – value of the identification criterion at site \( j \); \( IC_{RP} \) - value of the identification criterion of RP.

In the SMS, the HL are defined as locations where the number of accidents is higher than it would be expected according to their characteristics and, thus, could be treated for improvement. In the literature, various methods of HL identification can be found - see reviews, e.g., in Hauer (1996), Geurts and Wets (2003), PIARC (2003), HSM (2010). These methods can be classified according to the parameter applied as
identification criterion in Eq. (1), such as: accident frequency, accident rate, critical accident rate, equivalent property damage only index, relative severity index, combined criteria, excess predicted accident frequency using SPF, etc. (PIARC 2003; HSM 2010). To note, in the US Highway Safety Manual (HSM 2010) this parameter is termed "network screening performance measure".

In line with the state-of-the-art in road safety evaluations (Hauer 1997; Persaud et al. 1999; PIARC 2003; Bahar et al. 2003; HSM 2010), the method for HL identification should account for such phenomena as: the random nature of accidents; the exposure level - traffic volumes on the site; regression-to-the-mean; levels of accident severity. To exclude the impacts of the confounding factors, the HL identification should rely on an Empirical Bayes evaluation. By this method, the expected number of accidents at a site (or its safety level) is estimated as a weighted value of two components: (a) the mean number of accidents that expected on such type of sites (e.g. road sections with similar layout and traffic volumes); and (b) the number of accidents observed at this site in the past. The first component should preferably be estimated using a multivariable statistical model - SPF, fitted to local conditions (PIARC 2003; Bahar et al, 2003; HSM, 2010). Following Eq. (1), an HL is recognized using a high positive difference between the number of accidents expected at the site and that predicted for similar sites using SPF.

In addition, the form of relationship between the site traffic exposure and road characteristics and accident occurrences may differ for various accident severities (slight, serious, fatal), where accident severity has obvious economic implications. For example, PIARC (2003) showed that in the US the unit costs of fatal, serious and slight injury accidents were 2.6, 0.18 and 0.019 million US$, respectively, providing a ratio of 137:9.5:1 that can be used as weighted factors for estimating equivalent slight accidents for fatal and serious accidents. Similar estimates for Israeli conditions demonstrated (Gitelman et al. 2008) that the unit costs of accidents on rural road sections were 6.3, 0.89 and 0.048 million NIS (New Israeli Shekels; 1$=4 NIS) for fatal, serious and slight injury accidents, respectively, indicating a ratio of 131:18:1 (for rural road junctions, the ratio was 134:19:1). The typical accident cost units in Israel were received following the guidelines on the appraisal of transport projects (Nohal Prat 2006), where a major difference in the costs of severe versus slight injury accidents, both in Israel and other countries, stems from the adoption of a willingness-to-pay approach for estimating fatality and serious injury costs. The SMS procedure for selecting HL sites accounts for accident severities, where separate SPF were fitted for slight, serious and fatal accidents, and the potential for improvement of a site is estimated by means of weighting the difference between the number of accidents expected at the site and that predicted for similar sites, across the three severity levels.

The SMS procedure for selecting HL sites was developed in the Technion study (Gitelman et al. 2008), having examined the international experience and mostly following Persaud et al. (1999), Persaud (2001). The HL identification is performed separately for road sections and junctions, and includes four steps:

1. The expected number of accidents at a site is estimated by Empirical Bayes method, i.e. by weighting the number of accidents previously observed at the site and that predicted for this site (using SPF models), where the values are obtained for the three levels of accident severity, as follows:

   \[ m_i = (w_i \cdot SP_i) + (1-w_i) \cdot X_i/n \]  
   \[ w_i = \frac{k}{[k + (n \cdot SP_i)]} \]

   where \( i=1,2,3 \) for slight, serious and fatal accidents, respectively; \( m_i \) - the expected number of accidents at the site; \( n \) – the number of years for counting accidents at the site; \( X_i \) – the number of accidents observed at the site in \( n \) years; \( SP_i \) – the predicted number of accidents for this type of sites (using SPF); \( k \) – the estimate of uncertainty of the SPF models (the inverse value of the over-dispersion parameter of the negative-binomial regression model - see, e.g., Persaud et al. 1999).

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1 In line with international definitions, fatal accident includes at least one fatality, serious accident - at least one serious injury. Fatality is a person who died as a result of the accident, within 30 days; serious injury is a person who was hospitalized as a result of the accident for a period of 24 hours or more; any other person who was injured as a result of the accident but not hospitalized, or was hospitalized for a short period is defined as a slight injury.
The potential for safety improvement (PSI) of a particular site is estimated as the difference between the expected number of accidents at the site \( m_i \) and the predicted number of accidents for this type of sites \( SP_i \), where this value is obtained for the three levels of accident severity:

\[
PSI_i = m_i - SP_i
\]  

(4)

The summary value of the potential for safety improvement (Sum_PSI) of a particular site is estimated as a weighted sum of the values obtained in the previous step (PSI), according to the three levels of accident severity:

\[
Sum_PSI = \sum (PSI_i \cdot \lambda_i)
\]  

(5)

where \( \lambda_i \) – the weights based on the economic costs of typical accidents on rural roads which reflect the relation between the unit costs of fatal, serious and slight injury accidents, respectively (as explained above).

Rating the sites is performed in a descending order of summary potential for safety improvement (Sum_PSI). The sites with positive values of the index demonstrate a potential for safety improvement. The higher the index value, the site is more appropriate to be an HL. Initially, a threshold of "Sum_PSI > 2" was applied to selecting HL in the SMS. This means that the number of accidents expected at the HL site is higher by 2 or more (weighted) accidents, per year, compared to the number of accidents predicted for this type of sites with similar traffic volumes.

3 DEVELOPMENT OF SAFETY PERFORMANCE FUNCTIONS

For the SMS, SPFs were developed for single- and dual-carriageway road sections, and for various types of intersections: signalized/un-signalized, three- and four-legged. Due to the HL identification procedure's needs, for each type of sites three models were fitted, for various accident severities (but not differentiated by accident types). The models were developed based on accident data in three years, 2003-2005. Preparing the data, the road network was divided into short sections of 1 km in length, where, for each section, road type, traffic volumes and accident numbers were assigned; in total, 10,339 road sections (in three years) were considered. Similarly, data on 5262 junctions (in three years) were collected, including the type of control, configuration, traffic volumes (on main and secondary roads) and annual accident numbers.

First, the variance-mean relationship of the accidents, for each "site type - accident type" combination was explored, to check if there is a rise for negative binomial model (or at least Poisson model with an over-dispersion). For this stage we partially used the methodology suggested in Wood (2002). Typically, the quadratic relationship between variance and mean was observed in the data, supporting selecting a negative binomial model for the SPF development. Second, we explored what transformations of traffic volume should be included in each model of accidents versus traffic volumes. At this stage, we used generalized additive models, a powerful technique developed by Hastie and Tibshirani (1999), enabling to explore the form of the relationship between two variables. The exploration was done for each year separately due to dependency of accident data among years' problem. In most cases, we found that a log-transformation of traffic volumes best suited the data. Hence, the data distributions and the forms of their relationships were verified, during the models' development, using the above techniques.

The final models were fitted for each "site type - accident type" combination, using generalized estimating equations (GEE), for handling correlations among years. The models were developed using PROC GENMOD tools of SAS package, where GLIMMIX procedure of SAS was used to estimate the correlation parameters. The final model was a negative binomial regression model fitted to the observed number of accidents in site as the dependent measure. A negative binomial model belongs to the class of generalized linear models which are extension of traditional linear models that allows the mean of a population to depend on a linear predictor through a nonlinear link function. For sections, the independent measure was the logarithm of the traffic volume, where the logarithm of section length was used as an offset. For junctions, the independent variables were the logarithms of the main and secondary traffic volumes, where separate models were fitted to signalized and un-signalized sites. Due to non-convergence problems, the data from two intersection configurations, three- and four-legged, were modeled at the same mega-model, yet separately for sites with and without traffic lights.
For each type of sites, we modeled all three accident types (fatal, serious and slight) and all the three years simultaneously, in order to be able to estimate the correlations among the accident types and different years. For example, for sections, the linear predictor had the form:

$$\eta_{ijk} = \beta_{0i} + \beta_{1i} \log(V_{jk}) + \log(L_k)$$  \hspace{1cm} (6)

where $\eta_{ijk}$ is the logarithm of the predicted value of accident numbers for the $i$ accident type at section $k$ in year $j$; $L_k$ - length of section $k$; $V_{jk}$ – traffic volume at section $k$ in year $j$; $\beta_{0i}$, $\beta_{1i}$ are parameters to be estimated.

Table 1 provides an example of the model fitted to single-carriageway road sections. The interaction between traffic volumes and accident types was non-significant, meaning that the volume increase has the same multiplicative influence on all accident types. The SPF has the form:

$$SP = L \cdot e^{-9.6048} \cdot V^{0.9487} \cdot e^{I}$$  \hspace{1cm} (7)

where $L$ is the section length (km), $V$ – annual traffic volume (vehicles), $e$ – exponent, $I$ – coefficients of accident severity: $I= -2.2271$ for fatal accidents, $I= -1.2616$ for serious accidents, $I=0$ for slight accidents. This SPF predicts the annual number of accidents, of the three severity types, on a single-carriageway road section. The estimate of uncertainty of this model ($k$ in Eq.3) is $1/1.0126=0.9876$.

Table 1. SPF fitted to single-carriageway road sections

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>95% Confidence Limits</th>
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</tbody>
</table>

Notes to Table 1: $l\cdot V$ - logarithm of traffic volume, type - accident severity level (F fatal, S serious, L slight). Dispersion parameter was estimated by maximum likelihood. Dispersion = 1.0126 (0.741). Deviance: 9046.79 on 23876 degrees of freedom; log-likelihood: -7619.66.

Similarly, the SPF fitted for prediction of accident numbers on a dual-carriageway road section is:

$$SP = L \cdot e^{-10.4071} \cdot V^{-2.8110} \cdot e^{I} \cdot V^{0.1703} \cdot \ln(V)$$  \hspace{1cm} (8)

Concerning intersections, six groups of SPF models were developed, depending on the type of control (with and without traffic lights), level of traffic volumes on the main roads and the availability of data on traffic volumes on secondary roads (Figure 2). Each group of models includes SPF for two intersection configurations (three- and four-legged) and the three levels of accident severity. For example, the SPF fitted for prediction of yearly accident numbers on an un-signalized junction, with a traffic volume on the main road below 40,000 vehicles per day and no information on traffic volumes on the secondary road (group A in Fig.2), are:

$$SP = e^{-0.9427} \cdot (V1/11000)^{0.9706} \cdot e^{I} \text{ for three-legged junctions}$$  \hspace{1cm} (9)

$$SP = e^{-0.9362} \cdot (V1/11000)^{0.8171} \cdot e^{I} \text{ for four-legged junctions}$$  \hspace{1cm} (10)

where $V1$ – annual traffic volume on the main road (vehicles), $e$ – exponent, $I$ – coefficients of accident severity: $I= -2.2231$ for fatal accidents, $I= -1.4845$ for serious accidents, $I=0$ for slight accidents. The dispersion parameter of this model was 0.7151 (0.0621), providing $k =1/0.7151=1.3984$ (for Eq.3).

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In this model group, we used the value of $V1/11000$ instead of $V1$ in order to give meaning to the model intercept.

4 RESULTS AND DISCUSSION
Since the SMS introduction, the procedure of HL identification has been applied annually, serving as a basis for the preparation of the NTIC working program on infrastructure improvements of existing roads. The first application of the SPF models and the HL procedure produced a list of 337 km of road sections and 125 junctions that suited the HL definition (Gitelman et al. 2008). In the consequent years, the HL list was reproduced, based on the last three-year accident data. The SMS output is usually ranked according to the \( \text{Sum}_{\text{PSI}} \) values and serves as a basis for selecting the most problematic sites from the top of the HL list by using additional criteria, e.g. the total amount of accidents per 1 km should be over 8. Then, the sites are examined by traffic engineers to suggest road infrastructure improvements that could eliminate similar accidents in the future. The selection of treatments is based on the list of measures associated with proven accident-reduction effects (e.g. Gitelman et al. 2014). The HL sites are also compared with the lists of sites that were treated recently and with those included in the long-term plans of upgrading existing roads (to exclude a redundancy). Finally, the annual HL treatment program is composed, which typically comprises about 60 sites.

The SMS safety models stimulated a systematic work on the HL identification and treatment on the rural road network. Local evaluation studies demonstrated positive safety effects of such road infrastructure improvements on road safety. For example, Gitelman et al. (2014) reported that 19 types of road infrastructure improvements applied over the years 2007-2009, were associated with significant accident reduction factors and that the HL treatment project provided an average annual saving of 224 injury accidents. Among commonly applied treatments were: safety barrier improvements on roadsides, shoulder treatments, upgrading a single-carriageway to a dual-carriageway road section, building a roundabout, traffic lights' installation at a junction.

In many countries, HL or black-spots' detection and treatment is considered as important management tool for improving the safety level of existing road network (Geurts and Wets, 2003; Bahar et al, 2003). The European Union recently promoted a safety directive that requires road authorities to apply several tools for improving the safety level of national road infrastructure, one of which is the identification and management of HL sites (Directive 2008). The SMS activities in Israel actually comply with the European directive. Moreover, the HL identification procedure that was adopted by the SMS is based on the

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**Figure 2. Groups of SPF models fitted for prediction of accident numbers at junctions.**

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empirical Bayes evaluation, enabling to exclude the impacts of such confounding factors as exposure, infrastructure characteristics and regression-to-the mean. Such an approach is the most advocated today in road safety research (HSM 2010; Elvik 2012), whereas it is not common yet in the international practice (Sorensen and Elvik 2008). In the literature survey undertaken by Sorensen and Elvik (2008), some components of empirical Bayes evaluation were found in the HL identification methods of such countries as Finland, Portugal, Norway and the USA.

5 FUTURE NEEDS

The SPF models applied in the SMS were developed based on accident data recorded on the non-urban road network in 2003-2005. Over the years, a remarkable decrease in accident numbers was observed, in all severity levels. According to the CBS data (Table 2), in 2011-2012 compared to 2005-2006, the number of accidents on non-urban roads declined by over 20%, both among fatal and slight accidents, while the decline in the number of serious accidents was even stronger. These reductions can be related to improvements in road design practices, providing forgiving roadides, safer vehicles, better post-trauma care, improved young driver training, etc. As a result, the accident prediction models that were fitted to accident data about a decade ago are no longer suitable for providing a true estimate of the expected number of accidents on certain types of sites and, therefore, it is necessary to update the models, based on accident data recorded in recent years.

Table 2. The number of injury accidents on non-urban roads, in Israel, in 2005-2012

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>4449</td>
<td>4616</td>
<td>4202</td>
<td>4161</td>
<td>4350</td>
<td>3897</td>
<td>3614</td>
<td>3292</td>
<td>4532</td>
<td>3453</td>
<td>24%</td>
</tr>
<tr>
<td>Fatal</td>
<td>208</td>
<td>186</td>
<td>188</td>
<td>189</td>
<td>157</td>
<td>160</td>
<td>177</td>
<td>128</td>
<td>197</td>
<td>152</td>
<td>23%</td>
</tr>
<tr>
<td>Serious</td>
<td>657</td>
<td>653</td>
<td>573</td>
<td>535</td>
<td>503</td>
<td>426</td>
<td>333</td>
<td>417</td>
<td>655</td>
<td>375</td>
<td>43%</td>
</tr>
<tr>
<td>Slight</td>
<td>3584</td>
<td>3777</td>
<td>3441</td>
<td>3437</td>
<td>3690</td>
<td>3311</td>
<td>3104</td>
<td>2747</td>
<td>3681</td>
<td>2925</td>
<td>21%</td>
</tr>
</tbody>
</table>

Another issue that requires research is the way of road network subdivision into evaluation units, for HL identification. Initially, the SMS dealt with a fixed subdivision of the network into uniform road sections, of about 1 km in length. Gradually, it became more difficult to detect HL among the fixed road sections, raising the need for a dynamic segmentation of the network that would enable a better detection of accident concentrations due to adjacent accident locations (PIARC 2003). The US Highway Safety Manual (HSM 2010) illustrates a number of dynamic screening methods of HL identification and states their consistency with the empirical Bayes approach. However, the HSM examples refer to very short road segments, of 0.1 mile or similar, where such level of accuracy is not attained yet in accident recording, in Israel. Thus, the practical implications of a combination between the dynamic subdivision of the road network and the empirical Bayes approach, in the HL identification, still need to be explored, at least for the local conditions.

The SMS experience shows that with regard the HL identification procedure questions were frequently raised by the local decision-makers concerning such components of the method as the weights assigned to various accident types (on step 3) and the threshold value of $\text{Sum}_{\text{PSI}}$ for selecting HL (on step 4). Indeed, both components are not strictly defined in the international practice, leaving room for subjective judgment. It seems that running a sensitivity analysis of implications of various alternatives on the network level would be useful to support the selection of rules, in each case. In addition, in this framework, the issue of accident under-reporting can be accounted for, both at the stage of HL identification and justification of treatment measures. The awareness of the problem of under-reporting of road accidents, particularly with serious casualties, rose over the last decade, both in Israel and abroad (OECD/ITF 2012). Recently, this task became more realizable due to the development of quantitative tools that offer correction factors to the numbers of casualties reported by the police (e.g. Gitelman and Doveh 2011).

Finally, in the field of road infrastructure safety management, currently, an increase of pro-active activities can be recognized in the advanced countries, i.e. promoting tools that enable the identification of sites with higher potential for accident occurrences, due to infrastructure deficiencies or improper road design characteristics. Such tools include, first of all, various forms of safety inspections of existing roads and safety audits of new road designs as was recommended by the European Directive (2008). As indicated
by the European project RiPCORD-iSEREST (2009), the pro-active methods of improving road infrastructure safety become more relevant for countries that utilized the accident reduction potential of the HL treatment programs and where the sites with high accident numbers cannot be found any more. The SMS in Israel, in its current form, mostly apply reactive methods for improving road infrastructure. Thus, a wider implementation of pro-active methods for recognizing potentially hazardous sites should be considered in the future.

ACKNOWLEDGEMENTS

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INTRODUCTION

Losses and socio-economic impacts due to the traffic accidents, bring about crucial burdens on the countries. The need of an analytic method grows for selection of road safety measures based on operation performance, safety and cost effectiveness.

In this framework, Capacity-Safety-Cost Approach (CSC) makes a major contribution in finding a way out of road safety problems and the prevention of potential road accidents.

In this method (CSC), it is investigated road safety problems, risks and needs, reasons estimated and detected for these needs or problems, targets that are measurable and monitorable for both meeting needs and eliminating problems, do-nothing scenario, alternative solutions that will eliminate underlying causes of road accidents, preferred solution to traffic accidents, realized solutions’ level of success in reaching observable. The monitorable targets are assessed in a systematic way and practical results of this assessment are presented as suggestions for solution to the road safety experts who study in the application area.

SOLVING ROAD SAFETY PROBLEMS: A STRATEGY

Present practice

Traffic problems are often approached from a specific point of view. The road owner (authority, council) identifies a problem, a group of experts develop a solution and the owner takes a decision. Occasionally, involved parties such as residents, school boards, retail associations or councillors are given the opportunity to put their view forward. The danger of a one-sided approach is that not all aspects of the problem are sufficiently dealt with. Was a cheaper solution possible instead of the expensive traffic regulation system? Has the problem actually been solved? (SRD_manual) Are able to give a suitable level of service the selected safety measures? In this point, in this article, emphasis will be on road design in relation to road safety with special attention to design standards, accident analysis and cost-benefit analysis. A step-by-step method (POGSE) and a sub method (CSC) are described to lead from problem recognition to development of adequate and appropriate solutions included accident causes, goals, alternative solutions, capacity and safety performance and cost.

Policies

Road safety policy is in many countries a spearhead action. For instance: it is based on selecting and analysing black spots, giving special attention to vulnerable road users (pedestrians and cyclists) or predominant accident types (speeding, alcohol). In United Kingdom, Sweden, the Netherlands and Denmark this policy has proven to be very successful in reducing the number of accidents and fatalities. However, for continuing the downward trend in fatalities and injuries it is necessary to develop a more comprehensive approach, based on the interaction between humans, vehicles and the infrastructure. In the Netherlands this approach is known as “Sustainable Safety”. In Central and East European countries with high accident rates, due to the strong growth of car ownership and partly inadequate infrastructure, the spearhead policy seems to be the most cost-effective manner to start with.

Approach

The frustrations of interested parties not involved in the process should not be forgotten, nor the interminable discussions afterwards which come too late in the day. A great deal of unnecessary time
and money is wasted in this way, certainly if the situation has to be modified afterwards. Unnecessary because there is a better approach to traffic problems: POGSE. This is a simple aid to quickly and effectively analyse and solve problems. POGSE stands for Problem, Origin (cause), Goal (objective), Solution, Evaluation.

**Integrated approach**

POGSE is a coordinated approach, integrating a number of logical steps to solve the problems of traffic safety. It promotes consultation and active involvement of all parties concerned (the stakeholders) to systematically seek solutions to traffic problems. The starting point is the opinion that all stakeholders – with their traffic behavior and views on traffic – should play a role in seeking and finding the correct solutions. Communication and cooperation are just as important as traffic science and engineering.

With the POGSE approach all parties involved are assured of the opportunity for maximum input to the decision-making process. The POGSE approach saves time, money and frustration and provides demonstrably better results. In the Netherlands it is applied successfully in various situations, both simple and complex, to solve traffic problems [1].

The POGSE approach has many advantages. Most important, naturally, is the quality of the decision. The broad approach generally generates points of view that are overlooked in the one-sided approach. With the POGSE approach the various points of view can be carefully weighed up against one another.

The approach, simplified by the steps Problem-Origin-Goal-Solution-Evaluation, summaries the entire decision-making process. Contrary to the conventional approach, involved parties are not confronted with ready-made solutions, but they are given the opportunity to participate and react early on in the process.

**POGSE: step by step**

**Problem**

A problem is mainly related to a location (junction) or a road link. It can be determined on the basis of accident records, but may also follow from complaints of local residents. Insight is needed in the present and future function of the road or road links.

The trap of confusing the problem itself and the cause of the problem should be avoided. Consensus of the stakeholders on the real problem and the intended function of the road (link) are required before the next step is started.

**Origin (cause)**

When agreement regarding the nature of the problem is achieved; it is possible to proceed to the following phase: indicating possible causes. Opinions can differ drastically here between the stakeholders. Car drivers, for example, can be inclined to point to irresponsible cyclists’ behavior, while vice versa there are complaints about speeding by car drivers. At this stage, clear, independent research is indispensable. It is essential for all opinions to be considered, as more than one cause can lead to the identified problem. Also with this step, agreement on the cause(s) of the problem is a requirement before proceeding to the next step.

The analysis may concern:

- accidents (black spot analyses, see chapter 10);
- complaints (local residents, drivers, school boards, other pedestrians);
- traffic data (speeds, volumes);
- confusing road lay out;
• evaluation of measures (reconstruction or else) taken in the past (see the last step of the POGSE in this chapter).

**Goal (objective)**

Once problems and causes have been analysed and established, a common objective needs to be formulated. For example: within a certain period the number of accidents at a junction have to be halved, or cyclists are not to be mixed with fast speeding traffic on a particular road link. In every case, the description of the objective needs to include the highest achievable return.

If an agreeable objective cannot be specified, there is a danger of remaining on a too general level like “Improving the road safety”. Make sure the objective can be measured by defining a quantified improvement. In the evaluation the results of the measures taken (the solution) will be checked or audited against the goals identified in this step. When a specific, common goal is agreed, possible solutions can be identified and implemented, which is the next step.

**Solution**

This step is to devise possible solutions, in which the traffic expert has an important role. The input or basis for optional solutions are the conclusions of the previous steps (the goal in particular). The stakeholders may propose alternative solutions to facilitate discussions and decisions. The final choice is made considering the following:

- which solutions have the best effect (comes nearest to the goal or goals)?
- what is the cost?
- what is the level of operation performance?
- are other works foreseen to combine with specific measures?

**Evaluation**

Evaluation is the continuous monitoring of the effects of measures, followed by comparison with the set goals. Monitoring means collection and analysis of traffic data and accident data, complaints. Experience shows that implemented measures do not immediately lead to an improvement of the situation; it may even worsen initially. Evaluation is also very important to gather experience and knowledge about safety measures within certain circumstances. Comparison with the set goals means: an answer to the question whether results are as expected (do the results comply with the goals).

An evaluation period of three years is generally observed before definite conclusions are drawn. If found that the benefits are not satisfactory, the POGSE approach should be repeated, most probably leading to a refinement of the initial solution.

**HOW CAN ENGINEERING MAKE THE ROADS SAFER?**

Road crashes are almost always multi-factor events involving the driver, vehicle and/or the environment, including the road. There are many elements of the road that contribute to safety outcomes. These include road width, alignment, the presence of and type of intersections, and roadside hazards such as trees, poles and ditches. In the past, road safety has focused on the road user through enforcement and education. It is still crucial that we enforce safe limits on the road system.

However, it is also recognized that whatever we do to make drivers more alert, law abiding and competent, some will still make mistakes. They should not, however, have to suffer unnecessarily harsh crash outcomes, such as serious injury or death. We must work on designing and operating a road network that is more forgiving and protecting of driver mistakes and crashes.

By re-designing roads to make them safer, we can reduce both the number of crashes that happen and the severity of those that do occur. All risk cannot be eliminated through infrastructure and vehicle safety improvements alone. Drivers must always share responsibility for a safe road system.
Engineering measures can influence the messages we receive as drivers by making a road more ‘self-explaining’. Ideally, each type of road should have a recognizable and distinctive set of self-explaining features such as signage, lane width, road markings and speed limits. This ensures roads are predictable so that road users can expect particular safety features on each type of road.

To reduce the consequences of those crashes that do occur, roads can also be made more forgiving. Examples of specific road environment treatments, their potential effect on the four main crash types, and their relative costs are provided in Table 1.

Table 1: Potential reductions (%) in various injury crash types

<table>
<thead>
<tr>
<th>Alternative Solutions</th>
<th>Safety Problem</th>
<th>Cost</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>Head-on crashes</td>
<td>Run off crashes</td>
<td>Intersecton crashes</td>
</tr>
<tr>
<td>Road signs and delineation</td>
<td>25-40</td>
<td>25-40</td>
<td>25-40</td>
</tr>
<tr>
<td>Rumble strips</td>
<td>10-25</td>
<td>10-25</td>
<td></td>
</tr>
<tr>
<td>Central median hatching</td>
<td>10-25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed reduction (per 10 km)</td>
<td>15-40</td>
<td>15-40</td>
<td>15-40</td>
</tr>
<tr>
<td>Dedicated lanes for turning traffic</td>
<td></td>
<td>25-40</td>
<td></td>
</tr>
<tr>
<td>Removal of roadside objects</td>
<td>25-40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roadside barriers</td>
<td>25-40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder sealing</td>
<td>25-40</td>
<td>25-40</td>
<td></td>
</tr>
<tr>
<td>Roundabout</td>
<td></td>
<td>60+</td>
<td></td>
</tr>
<tr>
<td>Straighten alignment</td>
<td>25-40</td>
<td>25-40</td>
<td></td>
</tr>
<tr>
<td>Overtaking lanes</td>
<td>10-25</td>
<td>10-25</td>
<td></td>
</tr>
<tr>
<td>Divided roads and/or median barriers</td>
<td>40-60</td>
<td>40-60</td>
<td></td>
</tr>
<tr>
<td>Grade separated junctions</td>
<td></td>
<td>40-60</td>
<td></td>
</tr>
</tbody>
</table>

Note: $ \rightarrow$ Less than $50,000 per km or low cost, $$ \rightarrow$ $50,000 to $500,000 per km or medium cost, $$$ \rightarrow$ greater than $500,000 per km or high cost

WHICH QUESTIONS DOES POGSE AND/OR CSC METHOD ANSWER?

This method(s) provides answers to the following questions:

- Which measures can be used to reduce the number of traffic accidents or the severity of injury in such accidents?
- Which accident problems and types of injury are affected by the different measures?
- What effects on accidents and injuries do the various road safety measures have according to international research?
- What effects do the measures have on mobility and the environment?
- What are the costs of road safety measures?
- Is it possible to make cost- benefit evaluations of the measures?
- Which measures give the greatest benefits for traffic safety seen in relation to the cost of the measures?

Not all these questions are equally easy to answer, and it is not always possible to give a precise or conclusive answer. For example, the effect of a measure on accidents may vary from place to place, depending on the design of the measure, the number of accidents at the spot, any other measures that have been implemented, etc. As a result, different studies of the same measure may provide different conclusions. An attempt has been made to identify sources of variation in study findings and to try to form as homogeneous groups as possible when presenting estimates of the effects of measures on road safety.
While solutions to safety problems are produced, similar tables for effectiveness of safety measures, service life, cost and operating performance effects in different areas, should be prepared. These areas are road design and road equipment, road maintenance, traffic control devices, vehicle design and protective devices, vehicle and garage inspection, driver training and regulation of professional drivers, public education and information, police enforcement and sanctions.

CASE STUDIES
In this chapter, it is only shown engineering solutions.

Case Study 1 For POGSE & CSC Approach [5]

Problem: Intersection crashes are one of the most common types of crash problem, particularly in urban areas. In rural areas, or where vehicle speeds are high, the consequence of collisions at intersections can be particularly severe.

The chances of avoiding serious injury or death reduce dramatically above 50 km/h for side impacts for the most modern types of cars, and is far less than this for older vehicles, and particularly for vulnerable road users.

A number of different intersection crash types can occur, including:
- Collision between oncoming vehicles, particularly when one is turning across traffic
- Right-angle collisions, where neither vehicle is turning (often occurring at high speed)
- Right-angle or side-swipe collisions where one or more vehicles are turning
- Rear-end crashes

Origin: There are a number of causes of intersection crashes, including:
- Inadequate sight distance to on-coming vehicles
- High approach speeds
- Lack of intersection visibility (road users are not aware of the intersection)
- Lack of gaps in traffic
- Complex intersection layout
- Poor road surface condition

Goal(s): Reduction casualties 60% in 2 years

Solution(s): Possible solutions are listed below:

Table 2: Possible solutions for problems in case study 1

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Estimated cost</th>
<th>Casualty Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delineation</td>
<td>Low</td>
<td>10-25%</td>
</tr>
<tr>
<td>Intersection - Delineation</td>
<td>Low</td>
<td>10-25%</td>
</tr>
<tr>
<td>Intersection - Turn lanes (Signalised)</td>
<td>Low to medium</td>
<td>10-25%</td>
</tr>
<tr>
<td>Intersection - Turn lanes (Unsignalised)</td>
<td>Low to medium</td>
<td>10-25%</td>
</tr>
<tr>
<td>Parking improvements</td>
<td>Low to medium</td>
<td>10-25%</td>
</tr>
<tr>
<td>Skid resistance</td>
<td>Low to medium</td>
<td>25-40%</td>
</tr>
<tr>
<td>Speed management</td>
<td>Medium</td>
<td>25-40%</td>
</tr>
<tr>
<td>Railway crossing</td>
<td>Medium</td>
<td>60% or more</td>
</tr>
<tr>
<td>Intersection - Signalise</td>
<td>Medium</td>
<td>25-40%</td>
</tr>
<tr>
<td>One way network</td>
<td>Medium</td>
<td>25-40%</td>
</tr>
<tr>
<td>Intersection - Roundabout</td>
<td>Medium to high</td>
<td>60% or more</td>
</tr>
<tr>
<td>Traffic calming</td>
<td>Medium to high</td>
<td>25-40%</td>
</tr>
<tr>
<td>Intersection - Grade separation</td>
<td>High</td>
<td>25-40%</td>
</tr>
</tbody>
</table>

If selected measure is Roundabout, the needed information is that a roundabout is a one-way roadway around a circular central island. Entry to roundabouts is controlled by 'give-way' markings and signs. Vehicles already on the roundabout typically have right-of-way. Roundabouts cause little delay in low
to medium traffic flows, and require less maintenance than signalized intersections.

Geometric design is crucial to the safety of a roundabout. Curves on the approaches to require all vehicles to slow down before entering. The centre island layout ensures that traffic moves in a one-way direction and that slow speeds are maintained around and at exits to the roundabout.

The rules governing roundabout use also help to improve safety. Drivers approaching a roundabout need to slow and give way to vehicles already in the roundabout, and be prepared to stop. As a result, roundabouts can virtually eliminate often severe right-angle, left-turn (or right-turn), and head-on collisions.

Benefits will be provided:
- Minimal delays at lower traffic volumes.
- Little maintenance required.
- Crash severity is usually lower than at cross intersections.

Implementation issues are below:
- Solid structures should not be located on the central island.
- High painted kerbs around the island can reduce the risk of it being run into.
- Poor visibility on the approach to roundabouts, or high entry speeds, can lead to crashes.
- Facilities to help pedestrians cross the arms of the intersection should be provided in most urban locations.
- Roundabouts can be difficult for large vehicles, particularly buses, to use.
- Designers should be conscious of the risk that roundabouts can be present for cyclists and other slow vehicles, such as animal drawn vehicles.

Case Study 2 for POGSE & CSC Approach

Problem
In the last 3 years, traffic accidents has occurred with 8 dead, 10 injured and 20 vehicles vehicle damaged in K rotary junction located at intersection of AB main road & CD secondary road.

Other Inputs
- Annual average daily traffic (AADT) is 9,000 vehicles/day on main road and 6,000 vehicles/day on secondary road. It is estimated that after 10 years, AADT will be 15,000 on major road and 9,000 vehicles/day on secondary road.
- The budget is 1 million TL (1/2 million $)

Origin(s)
According to accident analysis, the main reason of accidents are high speed, side collision and run-off accidents.

Goal(s)
Building a safer intersection to prevent deaths within 6 months.

Proposed solution(s)
1. Increasing horizontal marking and vertical signing in existing intersection(estimated cost is 50,000 TL/25,000 $)
2. Elimination of vision problems on existing intersection (100,000 TL/50,000 $)
3. Building a new signalized intersection (250,000 TL/125,000 $)
4. Building a new roundabout (600,000 TL/300,000 $)
5. Building a new grade separated junction (3,000,000 TL/1,500,000 $)

Evaluation process and selection of suitable solution
- In this case study, it is predicted that weightiness of safety (S) is 40%, capacity (C) is 30% and cost (C) is 30%. (Note: The weightiness of safety, capacity and cost have to be determine the type of need. Shortly, if your need additional capacity, then, weightiness of capacity has to be higher than others).
Then the supply level of needs of solutions have been measured in terms of operating performance (capacity) and safety. The last step for this process is ranking.

### Table 3: CSC (capacity, safety and cost) effects of proposed solutions for the problem in case study 2

<table>
<thead>
<tr>
<th>No</th>
<th>Proposed solutions</th>
<th>Safety (40%)</th>
<th>Capacity (30%)</th>
<th>Cost (30%)</th>
<th>Total score</th>
<th>Implementation of priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Increasing horizontal marking and vertical signing on existing intersection</td>
<td>5</td>
<td>5</td>
<td>30</td>
<td>40</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Elimination of vision problems on existing intersection</td>
<td>5</td>
<td>5</td>
<td>30</td>
<td>40</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Building a new signalized intersection</td>
<td>15</td>
<td>20</td>
<td>20</td>
<td>55</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Building a new roundabout</td>
<td>40</td>
<td>30</td>
<td>20</td>
<td>90</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Building a new grade separated junction</td>
<td>35</td>
<td>30</td>
<td>5</td>
<td>70</td>
<td>2</td>
</tr>
</tbody>
</table>

Note: Firstly, the weight ratio for safety, capacity and cost parameters are determined. The nature of the problem is important while these ratios are determining in Table 3. If the basic problem is related to safety, the safety ratio has to be higher than others. On the other hand, if the basic problem is related to capacity, the capacity ratio has to be higher than others. Then alternative solutions for the problem are identified. For each alternative solution, the safety, capacity and cost points are scored out of 100 and then multiplied by their ratios. The ranking process is done according to the total score for each alternative solution.

According to POGSE or CSC approach, the most appropriate solution is “Building a new roundabout” and the second solution is “Building a new grade separated junction”

### Case Study 3 for POGSE & CSC Approach

**Problem (Need)** : In determination of junction type, there is a need for an analytical method that is combined capacity, safety and cost parameters in Turkey. Therefore, a working group of geometrical standards has been established within the body of Turkish Road Association in Turkey¹.

**Solution** : In this study, while the type of a planning junction is being determined, a model with two phases have constituted to balance safety, capacity and cost:

- Phase 1: This phase constitutes 6 steps. As seen Table, design speed, volume/capacity ratio, at grade intersection density, accident severity index, density of public transport stops and density of pedestrian crossing are evaluated on every steps. According to weightiness of step, GS (grade separated junction) and/or AG (at grade intersection) score is determined.
- Phase 2: If total AG score is higher than total GS score, then it is used Figure for the type of AG. In the contrary case, it is used Figure for the type of GS.

### Table 3: Determination process of junction types in case study 3

<table>
<thead>
<tr>
<th>Weightiness (30%)</th>
<th>Main road► Secondary road▼</th>
<th>Design speed (km/h) (Step 1)</th>
<th>Volume / capacity ratio (Step 2)</th>
<th>Weightiness (30%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Design speed (km/h) (Step 1)</td>
<td>Volume / capacity ratio (Step 2)</td>
<td></td>
</tr>
<tr>
<td>Weightiness (30%)</td>
<td>Main road► Secondary road▼</td>
<td>&gt;0.6</td>
<td>&gt;0.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>110</td>
<td>GS</td>
<td>1-0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90</td>
<td>GS-AG</td>
<td>&lt;0.6</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Data relevant to road safety are collected from a number of different sources including police reports and hospital admissions. This data can then be coded and entered on to a computerized database system.

Summary information on deaths and injuries (and in some instances, non-injury crashes) can be used to determine the scale of the safety problem in an area, country or region. However, more detailed information is required in order to determine the causes of crashes, and from this, the types of solutions that might be applied to address these problems. A variety of information is typically collected in the event of a crash. This might include location details, severity, driver factors (such as age of driver and passengers), vehicle factors, road environment factors (e.g. whether the crash occurred at an intersection, the types of road features present, weather conditions etc.) and contributory factors to the crash (e.g. speed, alcohol).

Examination of this detailed information can help identify key factors in crash causation, information that is critical in planning road safety actions. Details of crashes at specific locations can also be used to plan engineering based solutions and enforcement initiatives [6].

REFERENCES
1. DHV Environment and Transportation (2005), Sustainable safe road design A practical manual, file W0937-01.001, Registration number MV/SE2005.0903, version 5
ABSTRACT:
Safety issue has been receiving much attention for the long-term work zone projects due to increasing number of crashes within these locations. The impact of work zones on safety was investigated by many researchers. Except a few of them, the consensus is that the work zone presence causes an increase on crash frequency for a given roadway when compared to normal condition. However, this increase may not be distributed equally along the project duration.

The main hypothesis is that drivers who may not be familiar with a given mid or long term work zone at the beginning of these projects, then learn based on their day-to-day encounters with the same work zone conditions and adapt their behaviors accordingly. Thus, more crashes may occur for the initial period of the work zone projects. This hypothesis may be especially relevant when tested for rear-end crashes, the most frequent work zone crash type. Again nighttime shift may maximize the unfamiliarity for drivers for the initial period of a work zone project.

One way to test this novel hypothesis is to add the time indicator to the negative binomial crash frequency model. Since the “learning” in the initial period may vary by type or by duration of the work zone projects, a sensitivity analysis was performed to better understand the effect of the initial time period on the dependent measure.

Accordingly, the initial impact of the long-term work zones was investigated in this study, by using the negative binomial modeling structure employed for assessing work zone crash frequency. Comprehensive database was created by integrating information from project drawings, crash records and other sources. To clearly examine the work zone impact at the beginning of the project, “the initial impact” was included within the model as a dummy variable for belonging data. In addition to “the initial impact”, the following parameters were utilized within the frequency models; project length, light conditions, annual average daily traffic (AADT), posted speed, number of operated lanes, road type, number of ramps and intersection within the work zone. Different statistical models were developed; by using the number of total crash, property damage only (PDO) crash and injury crash outcomes. Preliminary results show that there is a significant relationship between initial period of the long term work zone project and increase in the number of crash. Moreover, severity risk is higher for the initial periods due to increase in the number of injury crashes.
BACKGROUND INFORMATION

In recent years, work zone safety has become essential with numerous highway renovation projects and a rising number of work zone crashes. Work zone safety is one of the most important issues for project contractors in terms of economic impact. Road user cost (RUC) estimations is included in the cost of work zone crashes. Incentive and disincentive amounts are estimated based on the RUC value which includes accident costs for construction zones (Zhu et al. 2009). Thus, estimating crash frequency at work zone sites is important for both safety and economical reasons.

Crash frequency at work zone areas was investigated in the literature to find out possible causative factors by using available parameters. Some of the previous studies are directly related to develop work zone crash frequency modeling. Variables used in these studies are mostly similar to the general crash frequency modeling approach. Negative binomial regression approach is preferred for modeling work zone crash frequency by using parameters such as AADT, duration, length and urban indicator, plus work zone type to determine contributing factors related to work zone accidents (Abdel- aty & Radwan 2000; Mitra & Washington 2007). Work zone specific parameters such as duration, number of lane closure, speed reduction etc. are included in recent studies for modeling work zone crash frequency (Ozturk et al. 2013).

The consensus based on the most part of the literature is that the work zone presence causes an increase on crash frequency for a given roadway when compared to normal condition. Juergens (1972) reported an increase of 7.0-21.4 percent for 10 work zone sites and Graham et al. (1977) reported an average increase of 7.5 percent for 79 work zone sites (Graham et al. 1977; Paulsen et al. 1978). Roupail et al. (1988) described an increase for crash rates of an average of 88 percent during the work zone period, and a decrease of an average of 34 percent in the period after their removal based on the before period crash rates. Hall and Lorenz (1989) found that crash rates increased by 26 percent during the construction period. Garber and Woo (1990) reported that the crash rates at work zones on multilane highways in Virginia increased on average by 57 percent and the crashes at work zones on two-lane urban highways in Virginia increased about 168 percent on the average. The research by Pigman and Agent (1990) also showed increasing crash rates on work zones in that 14 out of 19 work zone sites experienced increasing crash rates compared to the before period. Khattak and Council (2002) found that crash rates were higher in work zones with rates of 23.5 percent for non-injury crashes and 17.5 percent for injury crashes. All these studies overall work zone crash rates were based on the total duration of the projects. However, to evaluate the impact of the initial period at work zone sites is a novel approach among the literature.

Plotting crash counts by sequential periods provides an idea about the unfamiliarity effects of work zones on crash frequency. The temporal distribution of crashes was further investigated in terms of change in property damage only (PDO) and injury crash count rates. The main hypothesis is that drivers who may not be familiar with location at the beginning of these projects, then they can adapt to these locations day by day and take pre-actions before approaching these sites. Therefore, more crashes may expected at the beginning of the projects due to an unfamiliar conditions for the drivers.

This study aimed to find out the effect of initial period on the work zone crash frequency by modeling work zone parameters found at previous studies (Ozturk et al. 2014). The comprehensive dataset was used to model work zone crash frequency. The New Jersey crash data between 2004-2010 (NJDOT), plus 34 different long-term work zone project drawings and the NJ straight-line diagrams were combined to create the main database for modeling. Three monthly crash counts were used to set the models. Because of the dispersion of data, the negative binomial regression (Poisson Gamma) method was chosen for the modeling component. To implement hypothesis into model, time indicator for the initial period was added as a dummy variable. As can be seen from the Figure 1, there was a significant change for crash occurrence for the initial period of the work zone projects. Crash frequency was stabilized to non-work crash occurrence level after a while project start.
METHODOLOGY

The crash counts represent non-negative integers that are contributed to by several factors. To model such crash count data, a Poisson regression is used frequently among other statistical methods (Miaou et al. 1992; Lord et al. 2005). Beside this, there are several methods for modeling crash frequencies, such as the negative binomial (Poisson-Gamma) model, the zero inflated negative binomial and Poisson, truncated regression, the generalized additive model, the Conway Maxwell Poisson model, and the negative multinomial model etc. (Lord & Mannering 2010). Based on previous studies and data dispersion value, the crash frequency data for the work zones was modeled by using a negative binomial method, where the dependent variable was the three monthly crash counts observed within the work zones.

Let $Y_i$ represents the number of crashes at work zone $i$ for an exact length and duration, accidents occurrence for work zone $i$ is independent and probability density can be Poisson. (Green 1997; Khattak & Council 2002);

$$P(Y_i = y_i) = \text{Poisson}[\lambda_i(y_i)] = \exp[-\lambda_i] \frac{\lambda_i^{y_i}}{y_i!}$$

(1)

In the formulation, $y_i$ is realized number of crashes and $\lambda_i$ is expected crash frequency for work zone $i$. $\lambda_i$ represents explanatory variables such as duration, length and AADT. $Y_i$ s mean and variance values are equal to $\lambda_i$ which can be defined by Equation 2, where $\beta$ is the estimated coefficient and $x_i$ is the value of explanatory variables. Over dispersion is included by the error term $\epsilon_i$, which represents a random effect due to omitted explanatory variables and unmeasured heterogeneity.

$$\lambda_i = \exp(\beta x_i + \epsilon_i)$$

(2)

Safety performance function (SPF) for predicting the number of work zone crashes in an interval of given length and duration can be built as follows;

$$\ln(\lambda_i) = \alpha_1 \ln(L_i) + \alpha_2 \ln(V_i) + \sum_{j=1}^m \beta_j X_{ij}, \quad i = 1, ..., n$$

(3)

Where $\lambda_i$ is the predicted number of accidents in an interval of given length; $L_i$ is the work zone length; $V_i$ is the traffic volume during the period of study; $X_{ij}$ represents other explanatory variables; $\alpha$ and $\beta$ are model parameters. $L_i$ represents the work zone length.
DATA SOURCES

Spatial-temporal plots of work zone labeled crashes in the database were analyzed for major roadways of New Jersey. Visually defined work zones were verified by using project drawings in terms of project milepost intervals and timestamps. The New Jersey crash database between 2004 and 2010, 34 work zone project drawings and New Jersey straight-line diagrams were combined to form the main database for modeling the work zone crash frequencies. After directional separation of each work zone and the filtering of unclear data, 60 work zones were available for frequency modeling. Adjusted length for each work zone was decided upon by temporal-spatial analysis. Work zone crashes around project borders were captured and new mileposts for the border were defined by this adjustment.

Analyzing and merging of the data was processed by using the R package program. The R package program is able to merge a large dataset. Crash counts were clustered by 3 monthly periods for each work zone and separated into four crash categories: daytime PDO, daytime injury, nighttime PDO and nighttime injury crashes. Fatal crashes were included in injury crashes since the number of fatal crashes was small when compared to other two severity types. Categories and sample sizes are shown below in the Table 1:

<table>
<thead>
<tr>
<th>Category</th>
<th>PDO</th>
<th>Injury</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daytime Crashes</td>
<td>2915</td>
<td>862</td>
<td>3777</td>
</tr>
<tr>
<td>Nighttime Crashes</td>
<td>1192</td>
<td>413</td>
<td>1605</td>
</tr>
<tr>
<td>Total Crashes</td>
<td>4107</td>
<td>1275</td>
<td>5382</td>
</tr>
</tbody>
</table>

AADT is one of the most significant parameter for crash frequency models since it reflects the exposure of the traffic. Hence, accuracy of the AADT values is essential for modeling. Khattak and Council (2002) stated that directional AADT should be used for modeling to determine crash distribution more accurately. In this study, directional AADT values were selected from the NJ Straight Line Diagrams for given mileposts and within estimated time posts. All AADT values were adjusted seasonally by using NJDOT adjustment factors, and were also adjusted for nighttime and daytime traffic by using hourly adjustment factors. Bourne et al. (2010) reported an example of normalization issues for results that daytime work zone crashes are often overrepresented among all crashes. Nighttime traffic was approximately estimated as a quarter of the total daily traffic. Therefore, biased relationship between the AADT and crash counts was avoided by using reduced AADT for nighttime conditions.

Work zone length, milepost, number of operating lanes and lane closure information were obtained through project drawings. Work zone lengths were also checked by spatial-temporal analysis of the work zone crashes. Length values were adjusted by capturing work zone related crashes within the time post and milepost. NJDOT crash records provide seven different light conditions, however, for the sake of simplicity; these were categorized in two levels: daytime and nighttime. Work zone speed limits were gathered from NJ crash records according to the distribution of posted speed values within the work zones. Numbers of operated lanes information were obtained through project lane closure plans and decided upon by examining the most representative values during daytime and nighttime. Work zone speed reduction and lane drop parameters were generated by estimating differences between the work zone and normal conditions. Road types were categorized in two levels: interstate and state highways. Number of lanes, number of ramps and intersection for each work zones were obtained from NJ straight-line diagrams. The statistical summary of the 60 work zone sites is shown below in Table 2. Crash counts for each component were plotted with intersection and ramp information. Intersection and ramp milepost information was gathered from the New Jersey straight-line diagrams.
Table 2. Summary Statistics for Work Zones

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std.Dev.</th>
<th>Min</th>
<th>Max</th>
<th>(N=60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project length</td>
<td>1.85</td>
<td>2.33</td>
<td>0.12</td>
<td>10.20</td>
<td></td>
</tr>
<tr>
<td>AADT/lane</td>
<td>11.094</td>
<td>4.194</td>
<td>3.272</td>
<td>17.910</td>
<td></td>
</tr>
<tr>
<td>Ramp</td>
<td>3.35</td>
<td>3.45</td>
<td>0.00</td>
<td>15.00</td>
<td></td>
</tr>
<tr>
<td>Intersection</td>
<td>5.18</td>
<td>7.43</td>
<td>0.00</td>
<td>33.00</td>
<td></td>
</tr>
<tr>
<td>WZ speed</td>
<td>43.17</td>
<td>6.83</td>
<td>25.00</td>
<td>55.00</td>
<td></td>
</tr>
<tr>
<td>Speed reduction</td>
<td>7.83</td>
<td>6.27</td>
<td>0.00</td>
<td>20.00</td>
<td></td>
</tr>
<tr>
<td>Lane</td>
<td>2.62</td>
<td>0.65</td>
<td>2.00</td>
<td>4.00</td>
<td></td>
</tr>
<tr>
<td>Duration</td>
<td>759</td>
<td>395</td>
<td>90</td>
<td>1643</td>
<td></td>
</tr>
</tbody>
</table>

MODELING STRUCTURE AND RESULTS

The initial impact of work zones was investigated by using the similar modeling structure employed for assessing work zone crash frequency (Ozturk et al. 2014). To clearly examine work zone impact at the beginning of the project, the initial impact data was included within the model as a dummy variable. Three different statistical models were developed; the total crash, PDO crash and injury crash frequency models. The definition of initial impact was selected to represent the first three months period of the each project.

By using the created dataset from the work zone sites, the following parameters were included within the frequency models; initial impact, length, light conditions, annual average daily traffic (AADT), posted speed, numbers of operated lanes, road type, numbers of ramps and intersections within the work zone. The negative binomial technique was utilized to develop the model structure for the crash frequency. Below equation represents the modeling structure for the work zone crash frequency modeling for estimating “initial impact”.

\[
\text{crash\_count} = \exp(\beta_0 + \beta_1\text{initial}\_impact + \ln(\text{length})\beta_2 + \ln(\text{AADT})\beta_3 + \\
\beta_4\text{night} + \beta_5\text{intersection} + \beta_6\text{ramp} + \beta_7\text{wzspeed} + \\
\beta_8\text{roadtype} + \beta_9\text{operatedlane})
\]

(4)

The estimated results from the three different statistical models are provided within Table 3. The interpretation of the modeling results was considered at the 95 percent level of significance confidence interval. According to Table 3, all parameters were significant except, road system for total and PDO crash models, ramp for PDO and injury models, and dummy night factors for the injury models. Alpha values showed that the negative binomial was appropriate to use in this case as count data.

Table 3. Modeling Results for Initial Impact of Work Zones

<table>
<thead>
<tr>
<th>Crash Frequency / Variables</th>
<th>Total Crash Count</th>
<th>PDO Crash Count</th>
<th>Injury Crash Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>initial</td>
<td>0.204</td>
<td>0.000</td>
<td>0.178</td>
</tr>
<tr>
<td>ln(aadt)</td>
<td>0.659</td>
<td>0.000</td>
<td>0.669</td>
</tr>
<tr>
<td>ln(length)</td>
<td>0.496</td>
<td>0.000</td>
<td>0.522</td>
</tr>
<tr>
<td>night</td>
<td>-0.142</td>
<td>0.039</td>
<td>-0.196</td>
</tr>
<tr>
<td>intersection</td>
<td>0.015</td>
<td>0.000</td>
<td>0.015</td>
</tr>
<tr>
<td>ramp</td>
<td>0.018</td>
<td>0.039</td>
<td>0.011</td>
</tr>
<tr>
<td>psl</td>
<td>-0.021</td>
<td>0.000</td>
<td>-0.016</td>
</tr>
<tr>
<td>roadsystem</td>
<td>-0.042</td>
<td>0.561</td>
<td>-0.102</td>
</tr>
<tr>
<td>lanestd2</td>
<td>0.200</td>
<td>0.000</td>
<td>0.174</td>
</tr>
<tr>
<td>intercept</td>
<td>-4.076</td>
<td>0.000</td>
<td>-4.540</td>
</tr>
<tr>
<td>alpha</td>
<td>0.212</td>
<td>0.212</td>
<td>0.225</td>
</tr>
</tbody>
</table>
From the modeling results, work zone initial impact data for first three month period of the project was shown to include an initial period with a 22.7 percent higher frequency rate in terms of total crashes when compared to other time interval of the projects. Similarly, a 19.4 percent higher frequency rate was observed for PDO crashes and a 29.3 percent higher rate for injury crashes was found to be associated with the initial impact of the work zones on highways. Different from the previous crash frequency model, injury crashes were more numerous when compared to PDO crashes. Other parameters had similar impacts in terms of crash frequency models. Therefore, it can be concluded that there was no interaction between the initial impact and the other variables. If we look specifically at the data, a 1 percent increase in traffic caused a 0.66 percent increase in crashes, and a 1 percent increase in project length caused a 0.51 percent increase for each model. The AADT, which reflects traffic density per lane, was the most effective parameter in predicting work zone crash frequency. Length of the work zone was strongly associated with the number of crashes during the work zone period.

CONCLUSION & RECOMMENDATIONS

Since the “learning” in the initial period may vary by type or by duration of the work zone projects, an analysis was performed to better understand the effect of the initial time period on the dependent measure. In addition to the modeling work zone crash frequency, the initial impact was examined for the work zone sites. The initial impact indicator added model was developed for examining work zone crashes in more depth. Three different models were developed by using the negative binomial modeling regarding to work zone crash frequency data.

Based on the preliminary results, crash frequency for the initial period of the work zone was found 22.7 percent higher than that of the following time periods win the context of a work zone presence. This ratio was 19.4 percent for PDO crashes and 29.3 percent for injury crashes. This shows that familiarity of the work zone conditions over time reduced the risk of crashes. Especially injury crash ratio interaction with the initial period was almost 10 percent higher from the PDO crashes. Thus, extra caution should be deployed for the initial setup period of long term work zones to decrease number of work zone crashes.

ACKNOWLEDGEMENTS

The contents of this paper reflect views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents of the paper do not necessarily reflect the official views or policies of the agencies. The authors appreciate the partial support from the New Jersey Department of Transportation through the sponsored work zone safety project. The authors also thank for the insightful and constructive comments and suggestions by the anonymous reviewers to help enhance this paper.

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ABSTRACT:
Road safety & vehicle pollution is a major cause of concern in urban areas. With increase in number of vehicles every
day, there is tremendous pressure on traffic & vehicle movement. India has poor track record on driving patterns & road
safety. As there is no formal training & education on driving, most of the drivers continue to commit number of
mistakes on the road regularly. Over speeding, wrong overtaking, incorrect parking, poor hazard perception, fatigue &
tiredness, managing the rpm of the vehicle ( idling speed), not following the road signs, markings & other regulations,
not wearing seat belts & helmet, correct braking technique, are some of the mistakes which drivers continue to commit
on the road. These poor driving habits jeopardize the proper vehicle movement, slow the traffic due to sense less actions &
increase the risk of road accidents & fatalities. We propose drivers training programs to improve the driving skills.
These training programs should be aimed at various class of drivers & contribute to changing the attitude & behavior of
the driver.

The participants have realized the mistakes & started following better driving techniques. Besides the points mentioned
above, many participants also understood the importance of keeping safe following distance, 1-P-D-E rule, M-S-M rule
& 2 Seconds rule which help them to drive more carefully & defensively. Due to this training, they have committed
lesser mistakes on the road which helped in better vehicle movement & reduce traffic congestion to some extent thus
reducing the emission. The corporate sector has asked us to specifically develop such training specifically for the
movement in plants to minimize the traffic movement & reduce the emission levels. If the transport authorities make the
drivers training compulsory & ensure that regular training programs are conducted for all classes of drivers, there will be
major change in the driving habits which will reduce the traffic problems & congestion & thus reduce the pollution.
These programs are very low cost (training one driver cost US $ 6 per participant) which is negligible cost as compared
to benefits which are reaped. We have conducted more than 3900 such programs at various levels all over India &
neighboring countries & found the same to be very effective. The training is supported by number of films, animations,
visuals & questionnaires to focus on developing correct driving technique.
EFFECTIVE DRIVER’S TRAINING TO IMPROVE TRANSPORTATION & REDUCE EMISSION

1. INTRODUCTION

Indian economy is booming & the transportation sector is expanding very fast. It is estimated that 70% of the goods transportation in India is carried by road. With estimated 23 Mn. heavy, medium & light vehicles on road, there is a huge driver population. Driving a commercial vehicle in India is very tough and fetches meagre income for the drivers. Most of the drivers are either illiterate or have had primary education only. They are able to reach home only once or twice a month & spend most of their time on road. They need to drive continuously in rough / extreme weather conditions as most of the vehicles are non air conditioned. In addition to this, poor vehicle condition also affect their on road performance adversely. Due to such difficult conditions & non availability of a structured training/ awareness program, most of the drivers tend to commit number of mistakes on the road. As per the study, poor driving habits is the major cause & results into 80% of road accidents & crashes in India.

India has poor road safety record. The road crashes, grievous injuries are increasing in numbers & affecting the lives of all concerned. As per the data released by Minstry of Road Transport & Highways, the number of persons killed in road crashes in the year 2012 are 138258 where as people who had grievous injuries are 509667. India which accounts for just 1% of total vehicle population has the highest road fatalities of over 12%. These numbers are a concern as there is still no concrete program or step initiated by the Government to address this issue. Poor driving knowledge, lack of effective enforcement, casual attitude about driving non systematic road safety measures & haphazard growth of vehicles has contributed to this concern.

Courtesy: Ministry of Road Transport & Highways, India
In order to educate & impart knowledge on road safety & defensive driving, a classroom training programs was developed & conceived for commercial drivers. The programs are classroom sessions with commercial drivers who

- drive more than 12 hours daily. The programs are meant to educate these people about finer aspects of defensive driving. Topics like AIDS awareness, drinking & driving, tiredness & fatigue, following correct use of traffic rules, attitude of a safe drivers such as patience, confidence, anticipation & concentration while driving are explained in great detail. In addition to this separate programs are conducted for drivers of heavy vehicles carrying hazardous goods such as petroleum products. Some of the key points of such driver’s trainings are as follows:

- Program aimed specifically for heavy & medium vehicle drivers.
- It is conducted in local dialect for easy & convenient understanding of the topics
- The programs are supported by films & one to one discussions on the subject & to ensure maximum participation of every driver.
- We have also included some of the key benefits like reducing fuel consumption & controlling the pollution on the road.

Following benefits have been observed by conducting such Defensive Driving Training Programs:

- Reduction of road crashes & fatalities.
- Discouraging aggressive driving symptoms.
- Systematic driving which reduces the pollution & traffic congestion, thereby improving overall transportation on road.
- Highlighting the hazards of drinking & driving which was major cause of road crashes.
- Improvement in the fuel consumption & reduction in air pollution due to better driving habits.
- Holistic improvement in the driving attitude.

We have conducted more than 3900 such programs so far in India & abroad for commercials drivers & have trained approx. 240000 drivers on defensive driving techniques.

It has been observed that such programs have major impact on overall traffic standards & now the authorities of Transport Department have realized it’s potential & importance. They are setting up the process to conduct similar training programs for commercial drivers.

2. BACKGROUND & JUSTIFICATION:

In India, commercial driving is considered to be a very petty job. The pay scales & tough job conditions make this job very difficult. In India (& most of the neighboring countries) commercial drivers come from very poor & difficult backgrounds. If someone can not do any thing substantial in life he becomes a commercial driver. Life is very tough for them as they need to be on road for almost 25 days a month to earn their livelihood thus affecting their family life adversely. They need to adapt to the changing environment (which includes change in weather, food habits) regularly. In addition to the difficult background, most of the drivers are illiterate as most of them do not have inclination to study or simply refuse to study further. In addition to this, the process of granting a commercial driving license to a driver is not very well established/ followed by the Transport Department. Due to bureaucratic leniency in many cases the licenses are issued to a driver who does not have complete driving knowledge. These uneducated drivers do not understand the basic driving rules & do not follow them resulting in rash & negligent driving causing irreparable loss. These drivers also need to come to the office of Transport Department every 3 years for renewal of their commercial driving license but due to lack of any facilities of interaction/ training, they get their license renewed without any validation of specific knowledge and/ or updating their driving skills.

The most important impact on the drivers was when they started realizing the importance of quality driving. Driving in lane, parking at correct place, taking precautions while reversing, following correct road rules, wearing the seat belts, keeping a safe following distance are some of the factors which have made positive impact on them and which we believe has started contributing to better traffic management & transportation.
Effective driving skills, importance of defensive driving, fuel saving tips, drivers management & attitude which includes emotional and stress management have become the need of the hour for road safety & overall improvement in transportation. Conscientious driving, awareness & responsibility can be achieved through adequate knowledge, practical experience & regular monitoring, a task which has to be taken by authorities & trainers in India.

ACE Driving & Road Safety Education has initiated programs on Defensive Driving training in India. The programs are aimed to educate the illiterate drivers about the growing benefits of defensive driving on self, society & overall transportation system in general.

The training makes them aware about the road rules, hazards of driving for long hours (fatigue & tiredness issues), developing right attitude on the road & forewarning them about possible road hazards if they fail to drive recklessly. It has been observed that there is a marked improvement in such trained drivers, who try & follow many of the rules explained during the training thus reducing the probability of road crashes & fatalities.

The objective of explaining the road rules & their benefit for themselves & other road users has also been a positive influence on better traffic & transportation also.

The main issue involved in such an exercise is mobilizing the drivers & explaining them about such hazards so that they can be benefited from the training. Some of major issues involved are:

**Issues related to authorities/ policies:**

- There are more than 630 RTO (Regional Transport Offices) spread all over India which issue licenses (new & renewal) to approx. 40,000 persons every day & sheer number is such where the authorities has not initiated any step to handle training or drivers education.
- Poor infrastructure. The overall infrastructure in terms of roads layout, its maintenance, traffic bearing capacity etc., leaves a lot to be desired.
- Heterogeneous traffic. There is no limitation on the type of vehicles, speed & dimensions of a vehicle occupying the road. With a large spectrum of such diverse vehicles, the traffic gets affected adversely.
- The rules & penalties are dated. The penalty for violating a rule such as jumping a signal or parking at a wrong place is as low as US $ 2.2 (Rs. 100/-) which is not a deterrent for the driver any more.
- Limited number of traffic personnel is deputed for the duty. In almost all cases there is no traffic person available from 9 PM till 8 AM when traffic moves unregulated.
- Corruption at the lower level. Mistakes committed by the drivers are often overlooked after accepting bribe (of US 0.50 – 1).
- Complicated & state specific documentation/ formalities. For a vehicle to move across the country, the authorities often catch a vehicle for improper documentation thus affecting the whole schedule. Driver tends to over speed / commit more mistakes often to catch up the lost time/ schedule.
- The cost involved in conducting such training which requires personalized interaction, is steep & hence left untouched.
- As the numbers of drivers are very high, the authorities simply can not manage the training facility.

**Driver’s personal issues:**

- Reluctance in following road / traffic rules due to ignorance or sheer lethargy. The authorities too have priority where such rule violators are rarely caught & punished. Estimated only one out of 30 offender, subscribing to the incorrect road/ motor vehicle rules are caught & punished.
- General perception of committing mistakes & getting away with it.
- Unwillingness of the driver to participate in the program as there is no incentive for them to attend the same. Recently the Transport Department has taken an initiative to reward the drivers for participating in such training programs by bearing their food expenses & paying a sum of US $ 6 (approx) to them.
- The drivers are illiterate & hence are not willing to attend such training programs where their skills are likely to be tested.
3. DESCRIPTION

After realizing the importance & magnitude of the activity, the representatives of ACE met the National Safety Council of India & offered to work with them on this task. Simultaneously, we have also started gathering information, details of similar programs being conducted all over the world especially in the developed countries to educate & train the drivers. Unfortunately, most of the countries has Right side / left hand driving which ruled out much of the published material usage. Looking to the accident patterns, data on road crashes & fatalities, ACE has prepared a first cut defensive driving program way back in the year 1999 & started the road safety awareness & defensive driving programs at the premises of few corporate. This program was developed on transparencies & required Over Head Projector for the presentation. Since then, we start the programs on a very small scale for select corporate who were very safety conscious. After spreading the awareness to MNC’s & other safety conscious companies who realized it’s importance & relevance in the Indian driving context such as BP, Shell, Castrol, Reliance, Lubrizol initiated such programs for their fleet drivers. As their operations began to improve (higher efficiency, lower accidents) more & more companies asked us to conduct such programs for them. Soon the operations were spread all over India and we were invited to conduct road safety awareness programs.

Road Safety campaign conducted for heavy vehicle as well as hazardous goods drivers at Reliance Industries Limited, Jamnagar – India in the year 2011

We initiated steps such as making a drivers training program keeping the needs & requirement of an Indian commercial heavy/medium vehicle driver. We then customized the contents in following ways:

- The program was made in local language- Hindi so that majority of the drivers can understand the language. Later on it was developed in other regional languages also.
The program is supported by specific films created to facilitate the training. The film, first created in local Hindi language later on was dubbed in various other regional languages.

We developed the charts, road signs & other handouts in Hindi for better understanding of the participants.

Whenever it is possible, we conduct basic medical tests of the drivers so that any health problem if existing can be detected on time. If the driver has serious health concerns, we advise them not to drive further.

In many cases the program is supported by local statistics & recent crash details to make the audience realize the importance of the subject.

The programs have created good awareness among the drivers about correct driving practices & precautions they need to take while driving. Points like Road signs, road markings, other road rules like safe following distance, Mirror – Signal – Mirror & other safety rules are explained to them in detail.

The drivers claimed that they realized number of mistakes they were committing earlier. The awareness about fatigue & tiredness has been a landmark in our efforts & many companies have made a rule not to drive on road after 10 PM to avoid such crashes.

Training program conducted for commercial drivers at Hyderabad for Sygenta

Number of articles on road safety were circulated to create road safety awareness. Some of the Government department & agencies also asked us to provide them the support to conduct these activities on a regular basis. We also participated in seminars & workshops on the subject conducted by Society of Automobile Manufacturers (SIAM), National Safety Council of India (NSC) amongst others.

4. PARTNERSHIPS

The activity was a brain child of Mr. P N Helekar who himself is an expert on road safety awareness & has been trained at National safety Council, US on the subject. He started the activity of drivers training on a low scale in the year 1996 after retiring from the service at the age of 60 years. But soon due to his age & health limitations, he has created team of like minded people to take this cause further.

ACE Driving & Road Safety Education Pvt. Ltd., was formed in the year 2005 with the sole aim to train & educate drivers on safe driving.

Recently after realizing the importance of such training in India, Institute of Advanced Motorist (IAM Fleet), UK has shown interest in our activity & invited us to UK to share the training material & promote the activity manually. However the arrangement with IAM is purely on technical support having no financial involvement.
5. REPLICIBILITY

The driver’s training module is a very important tool to educate the illiterate drivers & spread awareness on road safety precautions. As the overall status of commercial drivers in terms of earning, living & overall livelihood is same all over the country, it is felt that these programs are very important to create road safety awareness & bring about progressive change in their lives & overall transportation system.

The program also highlights other factor such as road rules & lays stress on factors like positive driving attitude (which includes patience, confidence, anticipation & concentration on road). We feel that if the program is presented in the form of a short film/ presentation to all the commercial drivers who seek new/ renewal of their license at Regional Transport Office, it can make a huge difference to all the drivers & road safety.

By such a awareness, the overall transportation system in the city/ country will also have a positive impact & result into following benefits:

- Better, cohesive & regulated traffic.
- Better implementation of road rules & safety precautions
- Optimization of vehicle efficiency & overall driving standards
- Reduction in fuel consumption (due to better regulated traffic, better maintenance of the vehicle more cautious driving)
- Reduction in vehicle emission
- Reduction in road crashes & fatalities
- Mental peace

We have proposed to the Transport department of various states that ACE is willing to participate & conduct road safety awareness & safe driving programs for all the driving license applicants. However there is no legislation which enforces there applicants to undergo such a training/ awareness & also the cost implication for such a program on regular basis were major deterrents.

We have also proposed that every commercial driver has to undergo the following before granting new/renewal of the license:

- Medical Examination
- Passing the test about knowledge of road rules (Theoretical assessment)
- Undergoing & passing the individual driving assessment (Practical Assessment)

Though some points are discreetly covered but not actually followed currently. We have proposed such changes in the legislation & expect that Transport/ Local authorities would realize the importance of such work (would most certainly note this & initiate steps to modify the legislation.) . The results have bore the fruits & Government of Gujarat has approached us to conduct these training programs for all the commercial drivers (Taxi, auto rickshaws, truck & bus drivers) across the state thru their Regional Transport Offices to train & educate the drivers. We are scheduled to train 5000 drivers in the first phase & hopefully continue to train other drivers also on a regular basis.

6. LESSONS LEARNED

Some of the obstacles which are faced are:

- Reluctance in following road/traffic rules due to ignorance or sheer lethargy. The authorities too has priority where such rule violators are rarely caught & punished. Estimated one out of 30 offender, subscribing to the correct road/motor vehicle rules are caught & punished.
- Unwillingness of the driver to participate in the program as there is no incentive for them to attend the same. Recently Transport Department has taken an initiative to reward the drivers for participating in such training programs by bearing their food expenses & paying a sum of US $3 to them.
- The drivers are illiterate & hence are not willing to attend such training programs where their skills are likely to be tested.
As the number of drivers are very high, they simply can not manage the training facility. There are more than 500 RTO (Regional Transport Offices) spread all over India which issue licenses (new & renewal) to approx. 60,000 persons every day & sheer number is such where the authorities has not initiated any step to handle training or drivers education.

The cost involved in conducting such training is very steep as manual training is required & hence left untouched.

Many of the responsible organizations, corporate & individuals have realized the importance of the subject & now made it a mandatory exercise for their team/employees to undergo such a training. Now one of the Regional Transport Office has also realized the importance & accepted the proposal to organize such awareness programs for all the license applicants in their premises. The proposed program will be a shorter version & will be communicated thru audio–visual aids/films. The program will be developed in local language for wider acceptability.

7. FUTURE PLANS FOR EXPANSION

We are plans to improve the overall training & awareness activity by initiating following steps:

- To create a training module which is can run through for all the applicants.
- Planning some short films on training. These films in local dialect will be created keeping the local conditions, vehicles & road conditions in mind to generate more acceptability of the subject.
- We plan to hire more professionals into our organization (may be 2/3 trainers in each state) to conduct more such programs as requested by the corporate.
- We plan to launch the training sessions in select Regional Transport Offices initially. After the awareness programs are fully accepted by the authorities/participants, we plan to introduce this as an mandatory exercise for all the participants.
- To take support from other Government bodies, social organizations, NGO’s & other like minded bodies to support the cause.
- To penetrate the training at junior school & college level as youngsters also contribute largely for road crashes due to rash driving & poor driving knowledge.
- To have films created which can be shown on television & other media to create the required awareness.

We have already shared the information/activities with leading driving schools from other countries. We have had primary talks with driving schools like Singapore Safety Driving School, Singapore, Institute of Advanced Motorist, UK on sharing the data & details. We are willing to lend support to create such awareness among all the developing countries provided suitable platform & support is available.

We are also approaching various state governments & skill development departments to explore the possibility of extending these training programs for various sections of commercial drivers to promote road safety & defensive driving techniques. Government of Maharashtra & Madhya Pradesh has already shown interest in starting the training programs. We hope to conduct these training programs directly or thru our regional faculty members across India to train & educate 1 Mn drivers by 2020. This will be our contribution towards the decade of road safety as promoted by United Nations.

8. CONCLUSION:

The qualitative impact of the training programs is very positive. Many drivers who were never aware of such aspects have accepted that they were in fact driving dangerously & committing many mistakes on the road. Their driving has improved which must have created positive impact on the overall transportation & traffic. Though it can not be proved, but the road crashes also have reduced considerably & trained drivers seem to show positive attitude & confidence. The training program has good sustainability & can be replicated at all the Regional Transport Offices where the licenses are issued/ renewed. A widespread need of this driver’s education & awareness will most certainly improve the transportation as the attitude of the driver which comprises of Patience, Confidence, Responsibility while on road will be inculcated in him and he will be well equipped with technical skills and talent.

Road crashes were on rise & many organizations, corporate as well as individuals felt that it is necessary to create more awareness on such a vital subject amongst the commercial drivers who normally contribute most for such accidents. Some of the other factors are:
• Need for training/ awareness program aimed for the drivers.
• Change in traffic scenario & conditions. Improvement of roads in the country thereby increasing the speed of the vehicle
• Short cut of the process adopted while issue/ renewal of driving license
• Need to arrest the trend of such a trend & the cascading effect on the population, traffic in general & affected person in particular.
• Improvement in technology & introduction of new models

Such an exhaustive program is necessary in a society where drivers are major recruits in the employment sector, vehicle population & young drivers are on the rise & transport sector along with tourist industry is escalating in the developing countries.

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Highway safety: driver, vehicle, and roadway data

E.2 Data Collection and Diagnosis

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ABSTRACT:
The objective of the SHRP 2 safety focus area is to mitigate traffic injuries and fatalities by preventing, or reducing the severity, of collisions. To support that program effort, it was decided that a major aspect of the Safety Area of SHRP 2 would be to conduct a large-scale naturalistic driving study (NDS) to address the role of driver performance and behavior in traffic safety. This involves understanding how the driver interacts with and adapts to the vehicle, the traffic environment, roadway characteristics and other environmental features. Vehicle use was recorded continuously in the SHRP 2 NDS. Information on vehicle travel or, or exposure, can be extracted at the same level of detail as for safety-related events like crashes and near-crashes. Hence, the SHRP 2 NDS is the first large-scale study to support detailed estimates of collision risk.

The overall focus of this research was based on providing good quality data that are linkable to the vehicle and driver database (NDS) and stored in a secure, flexible database that is accessible utilizing geographic information system (GIS) tools. The Roadway Information Database (RID) will in essence provide the road element for safety research on the more than 5 million trips taken by the NDS participants. The data will support a comprehensive safety assessment of driver behavior and crash risk, especially the risk of lane departure and intersection collisions. The RID will enable safety researchers to look at data sets of selected road characteristics and study matching NDS trips to explore the relationships between driver, vehicle, and roadway. This capability of the RID makes it a very useful tool for NDS users interested in roadway characteristics and features because it allows researchers to focus on only those NDS trips that traversed road segments containing the items of interest. In addition, the RID serves as a template on how transportation agencies can integrate data from disparate sources in an effort to improve decision making beyond just safety; and the RID has the potential to serve as a template for a national integrated database to support decision making in a performance measurement environment.
Highway safety: driver, vehicle, and roadway data

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1 INTRODUCTION

To address the challenges of moving people and goods efficiently and safely on the nation’s highways, Congress created the Second Strategic Highway Research Program (SHRP 2). SHRP 2 addresses four strategic focus areas: the role of human behavior in highway safety (Safety); rapid highway renewal (Renewal); improved travel time reliability through congestion reduction (Reliability); and transportation planning that better integrates community, economic, and environmental considerations into new highway capacity (Capacity).

The objective of the safety focus area is to mitigate traffic injuries and fatalities by preventing, or reducing the severity, of collisions. To support that program effort, it was decided that a major aspect of the Safety Area of SHRP 2 would be to conduct a large-scale naturalistic driving study (NDS) to address the role of driver performance and behavior in traffic safety. This involves understanding how the driver interacts with and adapts to the vehicle, the traffic environment, roadway characteristics and other environmental features. Vehicle use was recorded continuously in the SHRP 2 NDS. Information on vehicle travel or, or exposure, can be extracted at the same level of detail as for safety-related events like crashes and near-crashes. Hence, the SHRP 2 NDS is the first large-scale study to support detailed estimates of collision risk. Moreover, crashes are a leading cause of nonrecurring congestion. Collision prevention has added benefits in terms of reduced delay, fuel consumption, and emissions.

For the exposure-based analysis approach supported by SHRP 2, characteristics of interest (such as roadway parameters) needed to be available for events, such as crashes, and for comparable driving segments where collisions did not occur. Due to the cost of mobile data collection, SHRP 2 was not able to collect roadway data using mobile data collection for all roads driven by participants in the Naturalistic Driving Study (NDS). Thus, it was anticipated that additional roadway data would come from existing sources in the public and private sectors.

The goal of this research project was to design, build, and populate a Roadway Information Database (RID) with data from the mobile data collection project, existing roadway data (from public and private sources), and supplemental data to help further characterize operations. The focus of this research was on providing good quality data that is linked to the NDS database and stored in a secure, flexible database, accessible utilizing geographic information system (GIS) tools. The RID will in essence provide the road element for safety research for the more than 5 million trips taken by the NDS participants. The data will support a comprehensive safety assessment of how driver behavior and performance might be impacted by roadway characteristics, environmental and vehicular factors, and the influence of these factors and their interactions on collision risk, especially the risk of lane departure and intersection collisions. The RID, through the use of dynamic segmentation, will enable safety researchers to look at data sets of selected road characteristics and study matching NDS trips to explore the relationships between driver, road, and vehicle. The six study sites where roadway data were collected are as follows:

- Bloomington, Indiana
- Erie County, Buffalo, New York
- Raleigh/Durham, North Carolina
- Tampa, Florida
- State College, Pennsylvania
- Seattle, Washington

In order to accomplish this goal, the following objectives guided the development of the SHRP 2 RID:

- Assess user needs.
- Re-evaluate mobile data collection vendors:
  - Develop short list to bid on request for proposal (RFP)
  - Determine vendor capabilities
- Develop project specifications for data collection and delivery.
• Conduct pilot data collection and evaluation on initial 900 centerline miles (out of 12,500 total centerline
miles) to refine processes and data accuracy requirements while assuring data were sufficient for safety
analysis.
• Conduct data discovery for existing roadway and supplemental data from government, public, and private
sources.
• Develop a data collection strategy for roadway information that complements the SHRP 2 NDS data and
supports exposure-based risk analysis as well as other safety analyses.
• Provide coordination and quality assurance for the collection and delivery of data by the mobile data collection
contractor.
• Acquire national basemap, existing roadway and supplemental data.
• Design, develop, and populate the SHRP 2 RID.
• Manage the RID for the duration of the SHRP 2 program including:
  o Supporting data analysis efforts requiring roadway data.
  o Developing basic long-term recommendations for database management after the SHRP 2 program.

This paper will cover the development of user and data needs, collection and quality assurance of data, other data
sources, database design, and conclusions.

2 USER AND DATA NEEDS

In order to identify the data requirements of the RID, potential users were identified. A key purpose of the user
identification effort was to facilitate the design of an integrated data set with data dictionaries suitable for stakeholders
who are most likely to use the RID for safety and other research. Users were categorized based on familiarity with
roadway data and familiarity with GIS and spatial analyses, and the type of analyses that will be conducted with the
RID.

The next step was to identify the roadway data elements necessary to answer research questions using the NDS data.
This effort included a broad range of safety-related research questions that users may ask. Webinars and a survey were
used to refine the initial list of potential RID data elements into a prioritized list. The final list consisted of critical items
necessary to help answer research questions related to run off road and intersection analysis. These data items were
collected as part of the SHRP 2 mobile data collection project and included the following:

• Horizontal curvature:
  o Radius
  o Length
  o Point of curvature (PC)
  o Point of tangency (PT)
  o Direction of curve (left or right based on driving direction)
• Grade
• Cross-slope/Superelevation
• Lanes: number, width, and type (thru, turn, passing, acceleration, car pool, etc.)
• Shoulder type/curb (and paved width, if it exists)
• All Manual on Uniform Traffic Control Devices (MUTCD) signs
• Guardrails/Barriers
• Intersection: location, number of approaches, and control (uncontrolled, all-way stop, two-way stop, yield,
signalized, roundabout). Ramp termini were considered intersections.
• Median presence: type (depressed, raised, flush, barrier)
• Rumble strip presence: location (centerline, edgeline, shoulder)
• Lighting presence

3 COLLECTION AND QUALITY ASSURANCE OF DATA

To assist SHRP 2 in the selection of a vendor to collect these data at highway speed, the research team used the results
from the 2008 SHRP 2 Roadway Measurement System Evaluation (Rodeo) project, and supplemented these results
with an additional evaluation that was conducted by the research team in 2010. This re-evaluation was accomplished by
documenting each vendor’s ability to collect roadway geometric data and some selected inventory data features on two
of the six Rodeo control sites. As a result, three vendors were invited to submit proposals to SHRP 2 in response to the
request for proposals for the mobile data collection project. Fugro Roadware was the selected vendor.
The objective of the mobile data collection project was to collect high-quality data on those roads most frequently driven by NDS participants and on roads of greatest interest to safety researchers. Guidance was developed both for the allocation of total road data collection mileage apportioned to each of the six NDS sites and for allocation within each study area. Allocation within each study area was determined using a sample of global positioning system (GPS) traces from the NDS participants’ vehicles and focused on rural two-lane roads. Coverage for each NDS site is provided in Table 1.

Table 1. Miles collected in the mobile data collection project

<table>
<thead>
<tr>
<th>NDS site</th>
<th>Miles collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida</td>
<td>4,366 miles</td>
</tr>
<tr>
<td>Indiana</td>
<td>4,635 miles</td>
</tr>
<tr>
<td>New York</td>
<td>3,570 miles</td>
</tr>
<tr>
<td>North Carolina</td>
<td>4,558 miles</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>3,670 miles</td>
</tr>
<tr>
<td>Washington</td>
<td>4,277 miles</td>
</tr>
</tbody>
</table>

A major effort throughout this project was providing coordination and quality assurance (QA) for the collection and delivery of data by the mobile data collection vendor. For this purpose, a QA plan was developed. This plan outlined the processes to ensure optimum data quality from project setup to final data delivery and acceptance by SHRP 2. In addition, the QA plan defined the accuracy requirements and tolerances for what was deemed a non-conforming product and the process to deal with a non-conforming product. The QA process involved random site visits. Ground truth reference measurements were taken in the field throughout the project period, and a custom process was developed for checking and analyzing the accuracy of the mobile data by using GIS tools. In addition, to ensure the data collection equipment was operating properly, control sites were set up in each of the six NDS sites. The vendor collected data on these control sites during specific stages in the data collection cycle, and the research team verified the results against ground truth data.

The quality assurance included two processes performed simultaneously; one analyzing roadway features, the other analyzing alignment. The first process utilized control sites and random sites (described below) where all roadway features were collected. These roadway features were as follows (Figure 1):

- Intersections (location, type, number of approaches, control type)
- Signs (MUTCD code, speed limit value, image)
- Highway lighting (presence)
- Lanes (type, width)
- Medians (presence, type)
- Shoulders (type, width)
- Rumble strips (presence, type)
- Grade and cross-slope values
- Barriers (barrier type, start/end treatment type, post material, rubrail)

The second process analyzed the alignment (tangent, curve) for the accuracy of the radius. For the control sites, the curvature data was obtained from the DOTs. For the random sites, this process was completed using the GPS traces from the mobile data collection vendor to determine the chord and length of curve which was used to determine the radius.
Table 2 provides a summary of the required minimum accuracy requirements that were used to complete the quality assurance for the mobile data collection project. The pilot data collection conducted in 2011 was critical towards establishing the data collection process, determining feasibility of minimum accuracies, and testing the quality assurance process.

Table 2. Required minimum accuracy requirements

<table>
<thead>
<tr>
<th>Data Element</th>
<th>Accuracy Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curvature Length</td>
<td>100 ft. (curves less than 1,500 ft. radius)</td>
</tr>
<tr>
<td></td>
<td>250 ft. (curves between 1,500 ft. and 6,000 ft. radius)</td>
</tr>
<tr>
<td></td>
<td>Within 13% (curves over 6,000 ft. radius)</td>
</tr>
<tr>
<td>Curvature Radius</td>
<td>100 ft. (curves less than 1,500 ft. radius)</td>
</tr>
<tr>
<td></td>
<td>250 ft. (curves above 1,500 ft. radius)</td>
</tr>
<tr>
<td>PC</td>
<td>50 ft.</td>
</tr>
<tr>
<td>PT</td>
<td>50 ft.</td>
</tr>
<tr>
<td>Grade (+ or -)</td>
<td>1.0%</td>
</tr>
<tr>
<td>Cross-Slope/Superelevation</td>
<td>1.0%</td>
</tr>
<tr>
<td>Lane Width</td>
<td>1 ft.</td>
</tr>
<tr>
<td>Paved Shoulder Width</td>
<td>1 ft.</td>
</tr>
<tr>
<td>Inventory Feature Location (signs and barriers)</td>
<td>7 ft.</td>
</tr>
</tbody>
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The mobile data collection project covered about 12,500 centerline miles in the six NDS sites. Because data were collected in both directions of travel, a total of approximately 25,000 miles was provided. Below are summary statistics from the mobile data collection project. These data were collected consistently and within project specifications across the six NDS sites.

- **25,076** total miles of roadway data collected
- Total number of assets, including grade and cross-slope points: \(7,524,310\)
  - 44,114 curves
  - 6,129 miles of barriers
  - 43,195 intersections
  - 7,376 miles of highway lighting
  - 10,756 miles of medians
  - 33,013 miles of paved and unpaved shoulders (this number includes inside and outside shoulders on four-lane divided roads)
  - 11,852 miles of rumble strips
  - 518,570 total signs

4 OTHER DATA SOURCES

In addition to the data from the mobile data collection project, roadway data from existing public resources (e.g., Highway Performance Monitoring System [HPMS] data and comprehensive data items available from state transportation agencies) and a list of supplemental data items were acquired and included in the RID. The term “supplemental” refers to any data item that characterizes a roadway segment that was not included as part of the mobile data collection undertaken by SHRP 2 or existing roadway data acquired from transportation agencies within the six NDS sites. These supplemental items included crash histories, traffic, weather, work zones, changes to infrastructure, aerial imagery, Federal Railroad Administration (FRA) grade crossings, safety enforcement laws, and active safety campaigns. The existing and supplemental data that were acquired are estimated to cover about 200,000 centerline miles within the six NDS sites.

5 DATABASE DESIGN

The RID design is a simplified version of the revised Unified Network-Transportation (UNETRANS) network data model. Data models, technical specifications, and supporting management components were developed to define the RID and to ensure its interoperability with the NDS database. The RID was built on an underlying, route measure-based linear referencing system (LRS). Other roadway features, such as those collected as part of the mobile data collection project, have been conflated to this LRS and are represented as individual features within an Esri ArcGIS Geodatabase. Each feature also possesses corresponding LRS-based route and measure values. Therefore, the RID supports both attribute- and spatial-based queries as well as dynamic segmentation. Even though the RID is built as an Esri ArcGIS Geodatabase, other GIS software users can still utilize the RID.

All the data contained in the RID are referenced to a national basemap, which provides a consistent centerline across the six NDS sites. This design allows the users, through the process of dynamic segmentation, to produce road segments with any variable of interest from the various data sets contained in the RID. Figure ES.1 shows an example of using dynamic segmentation to select two-lane rural curves in North Carolina with paved shoulders less than 6 ft. Figure 2 shows how out of 8,414 total curves, only 854 curves meet the selection criteria, which in turn helps focus the research questions and provide a more efficient and convenient process to request NDS data.
Figure 2. Dynamic segmentation to select a set of curves in NC

When the RID is completed in December 2014, a user guidance document, which includes data sources, query examples, roadway-linked NDS data examples, and a step-by-step process to integrate additional data into the RID, will be provided along with the database. In the meantime, please see Appendix F, which provides a step-by-step process on selecting specific roadway characteristics using RID and dynamic segmentation.

6 CONCLUSION

Overall, the RID design and included roadway data achieved the project goals and objectives. The addition of the supplemental data to the RID enhances the users’ ability to conduct a more comprehensive analysis than just roadway inventory data could provide. Using a consistent and comprehensive road network has provided the users of the RID and NDS the ability to conduct analysis across multiple sites. In addition, the RID design provides a template that transportation agencies can use in considering how to integrate disparate data to support safety, asset management, planning, and operations activities.

As with any other effort, there were some challenges and lessons learned throughout the process. The following describes the challenges faced and the lessons learned:

1. The SHRP 2 safety study was the largest of its kind to date, and building the RID to address multiple research questions was complex and required major tradeoffs between cost, time requirements, and complexity of the system. The research team used existing safety literature, SHRP 2 safety projects that developed research questions, and input from researchers covering a wide range of safety research to develop a list of critical roadway attributes to be collected.

2. The discovery of existing data (whether state, local, or private sources) proved very beneficial to the RID. There were challenges in terms of data access and sharing for non-state DOT data that limited the amount of data that ended up being acquired as part of the RID.

3. Evaluating mobile data collection technology and services is not a trivial task. Knowledge of the users’ requirements, funding constraints, and accuracy requirements is critical to selecting the right contractor for the job. In the end, the team, in cooperation with SHRP 2, was able to qualify three contractors to submit proposals for roadway data collection.
4. With six study sites around the U.S., it was critical to use a consistent roadway network to build the linear referencing system for the RID. Utilizing the Esri/NAVTEQ road network made it possible to integrate and link data from different sources for the RID and enabled the linking of the RID and NDS data.

5. Developing a process for selecting roads for the mobile data collection in each site allowed the research team to optimally allocate the collected miles between sites and within each site. Using GPS traces from the volunteer drivers made it possible to select roads where NDS participants drove. Using GIS tools was critical to making this process work smoothly and efficiently.

6. Collecting quality data was deemed paramount to the success of the RID. Even though only the data collected through the mobile data collection project went through the quality assurance process, these data will provide researchers with the most accurate roadway information available across multiple sites. The quality assurance process was the result of constant communication and coordination between the team conducting the quality assurance and the team collecting the data.

7. The pilot data collection effort was a key aspect in successfully acquiring the mobile data on such a large and dispersed scale. This small-scale effort provided the research team with the necessary information to improve and customize the process for routing, collecting, processing, and conducting quality assurance.
The operator in control: aware of internal processes

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ABSTRACT

Do you know how to respond when approached in a stressful situation, such as a tunnel incident? In these types of situations, the ability to make the correct decisions at the correct moment is crucial. Tunnel organizations spend millions in technology for tunnel safety. Operators are trained and educated to work with these safety systems. After incidents and calamites incident evaluations reveal opportunities to improve safety. The conclusion of these evaluations are often that things went wrong by a lack of human performance. It turns out that tunnel managers involved with a tunnel calamity act different in stressful conditions than in normal circumstances. It also shows that the perceived stress by the same tunnel manager can be different in similar incidents.

Understanding of his own primal reaction to stress and recognizing raised stress levels when it happens allows the operator to intervene and adapt a suitable strategy, based on contentment and aimed at helping others. This process can be trained!

A practical training module helps operators to get a grip on their tension. Operators interact with one of our simulation actors (that is already tension enough). The simulation actor creates an atmosphere of lightly raised stress. Operators experience their primal reaction on the situation: freeze, fight or flight. We ask them where they feel the stress in their bodies and we help them with the relaxation of that stress.

Early recognition and anticipation of the primal reaction along with the right techniques, can do a great deal to keep the communication in a professional manner and perform as planned.

Tunnel managers who have successfully completed this training are able to take responsibility for their decisions and understand the consequences of their behavior. Training Human Performance and Effective Communication in tunnel incidents and calamities, empowers operators so that they stay strong and clear in their communication during incidents and calamities. It enables the operator to use the safety systems, work with the procedures and enables him to work with less or malfunctioning technology and in doing so improve the outcome of the incident.
INTRODUCTION

Over the last 25 years much research has been conducted into incidents and disasters in tunnels. After the serious disasters in the Mont Blanc Tunnel (1999) and in the Kitzsteinhorn tunnel (2000), many improvements in tunnel safety were carried out. These improvements are mainly within the technical aspect of tunnel safety: detection systems, ventilation and escape possibilities for users have been improved and measures and procedures for operators have been revised.

The research also looks carefully at the role of the tunnel operator (hereafter called “operator”) and the role of the road user. Insight into the action and inaction of the road user has led to many adjustments to procedures and protocols. The role of the operator has been carefully studied and analyzed. In the procedures that help the operator in preventing incidents, important points of improvement have surfaced and been implemented in the operator protocols. This has contributed to an increased self-rescue phase and consequently to a reduction in the seriousness of incidents.

However, using elaborate and detailed procedures and protocols brings with it the risk that the operator makes mistakes. J. Rasmussen (1988) identifies three types of human failure: Skill-based, Rule-based and Knowledge-based errors. The solution Rasmussen suggests to prevent such human failure is to improve procedures and make ergonomic adjustments.

In the extensive UPTUN research by P. Papaioannou and G. Georgiou (2008) attention is paid to the role and behavior of the operator during an incident and here too the recommendations are mostly of a process-based nature. The EU research project UPSAFETY (2011) provides clear guidelines and a standard format for an Education, Training and Practice program ensuring that operators and first responders know the procedures and protocols, thus reducing the risk of human failure by first responders and operators.

NEUROPHYSIOLOGICAL PROCESS AT THE BASIS OF OPERATOR RESPONSE

All research up until now neglected the neurophysiological process that influences decision making. This article focuses on this neurophysiological process: the subconscious process that lies at the basis of the action or inaction of the operator. This process is also the basis of stress and occurs with the operator before and during an incident or calamity. It is comparable with the action or inaction of road users in a tunnel incident.

It is a process within the brain that lies at the basis of human failure. We will provide a clear insight into this process and we will describe how we successfully bring it to the attention of the operators, making them more aware of their actions and ultimately saving lives. Because this process also occurs with road users, it is of vital importance that the operator is made aware of this ever-present mechanism and of the techniques that help him to continue to function properly.

TENSION, STRESS AND THE WORKINGS OF OUR THREAT/SELF-PROTECTION SYSTEM

There are many definitions of stress. In a general sense, stress is the reaction to a stimulation that causes tension. Within the context of this research, we regard stress as a process that is caused by a stressor (the condition that triggers the stress) and it is the reason for the stress response (the reaction to the stressor).

Research by Joseph LeDoux (1998) indicates that a small part of our brain is involved in the regulation of negative emotions, the amygdala. This almond-shaped core is located in the temporal lobe and is part of
our limbic system. The amygdala establishes connections between information from different sensory inputs and links these to emotions (internal stimuli).

Information reaches the amygdala in two ways:

- The direct way (Low Road according to LeDoux)
- The indirect way (High Road according to LeDoux)

The direct way is shorter and therefore faster than the indirect way but, on the other hand, also gives less precise information. The direct way transmits information through the thalamus directly to the amygdala and enables us to react before we know exactly what is happening. The thalamus is our reptilian brain, the oldest part of our brain.

This primal instinct is useful for, amongst other things, defense and hunting. In dangerous situations it is of great benefit: you fight or you flee. In primitive times, when a wild animal approached, this was a useful response. However, when this system is triggered without the presence of a direct threat, the fight-or-flight response can be a hindrance (MacLean, 1990; Hanson, 2009).

The indirect way transmits information through the thalamus to the neo-cortex. The neo-cortex analyzes the information before it is sent through to the amygdala. The thalamus acts as a filter for external and internal stimuli (emotions) before transmitting these to the neo-cortex, which generates a more detailed representation of the information. This process takes more time than the direct way.

This more time consuming approach takes place in a newer part of the brain, the so called neo-mammalian brain. This is the youngest and most flexible part of our brain, where development and adaptability reside. The processes of analysis, insight, learning and development take place here.

As soon as we spot danger, the amygdala engages the hypothalamus, which in turn tells the pituitary gland to produce stress hormones. These hormones prepare the body for fight or flight. Physically, this manifests itself in an accelerated heartbeat, faster flowing blood, increased muscle tension, and the quickening and shortening of breath.

**Consequences of stress**

The hypothalamus also activates the sympathetic nervous system. The sympathetic nerves are responsible for the production of adrenalin. This adrenalin makes your heart beat faster, causes you to sweat and energy to be directed to your arms and legs. This is necessary to flee or fight.

When stress is prolonged, or presents itself too often, it will cause you to slowly exhaust yourself. The body is literally in a constant state of readiness for fight or flight. The produced adrenalin cannot drain off and tension builds. This causes an unhealthy and unnecessary tension, which can eventually lead to burnout.

**Learning ability and stress**

Our body is an intelligent system. Many of our daily activities, some of which are quite complex, have been learned, never to be forgotten again. We are not consciously aware of many of the tasks and actions we perform regularly. Ultimately, the learned action is performed without thought. For example, the use of a computer keyboard, and tapping the keys on that keyboard, happens automatically. Nevertheless, an
ingenious mechanism lies at the basis of this. Another characteristic of our body is that it learns from experiences and remembers that which it learns. If you are in a scary situation and your subconscious impulse is to flee, then recollecting that occurrence is enough to provoke a similar physical response. Our body learns from events. This process can be observed in operators in their experiences with incidents. A simple rear end collision will, when first experienced, release stress hormones and put the amygdala to the test. During a second rear end collision our body will immediately refer to the earlier experience and adjust its response appropriately. Less stress hormones are released and we will be better able to use the information from the neo-cortex. We are more conscious of our actions and decisions.

It is possible to acquire this learning ability, which our body is already subconsciously applying, for use in unexpected situations. By putting our body in a simulated, unknown stress situation the stress reaction is brought out. Our brain is constantly communicating with itself and with the rest of our body in order to analyze and preserve contact with the external environment and intervene where necessary. An important element in this relationship is our internal “emergency button”: fight, flight or freeze. This reaction is subconscious; we cannot turn it off. We can train to become conscious of that subconscious mechanism. This causes an awareness of the internal process and gives the possibility to intervene earlier in the fight-or-flight-or-freeze response and to give preference to the information coming from the neo-cortex.

By being present, with full attention, in the here and now, we can remain in contact with our body (physical stimuli) and with our mind (physiological process). This insight provides the best chance to fully understand your own reaction and make a rational choice that has the most chance of providing an effective response.

Man has a rational way of thinking, which functions well if it is not disrupted too much by tension that he has no way of dealing with. As soon as an event causes a disturbance, the mechanism that prepares for conflict is triggered. For an operator who needs to function, this mechanism is not wanted.

The mechanism that drives the fight-or-flight-or-freeze response

Emotion is a response of our brain to an affective stimulus. This manifests itself in behavior and physical reaction. These reactions can be conscious and subconscious. From an evolutionary standpoint, all emotions are useful. While our emotional life is complex, it is possible to distinguish three basic types of emotion regulation (Gilbert 2009).

- **THREAT/SELF-PROTECTION SYSTEM**
  This system is activated by threat and danger. It is aimed at self-protection and survival. This system originates from our reptilian brain. The primary impulse responses fight, flight or fright stem from this system. Accompanying characteristics are: production of adrenalin, quickening of the heartbeat, blood flowing faster, breaths becoming shorter and saliva production halting. These are all signals that indicate the body is preparing for fight or flight. Reason is not functioning.

- **INCENTIVE/RESOURCE-SEEKING SYSTEM**
  This system is activated by desire (food, success, ambition, power). It is aimed at instant gratification. The body is focused. Physical characteristics depend on the desire that needs to be fulfilled and can include: accelerated heartbeat, increased muscle tension and an abundance of energy. The incentive/resource seeking system is concerned with one’s own fulfillment and not primarily aimed at others. It causes a constant search for new challenges and costs a lot of energy.

- **SOOTHING/CONTENTMENT SYSTEM**
This system is activated when other systems do not need to be. When the body does not have to be on the lookout for threats and no desires need to be fulfilled, the soothing/contentment system can be utilized. This system originates from our neo-mammalian brain and is concerned with safety, connectedness and well-being. The system provides, amongst other things, the possibility for reflection and development. A physical characteristic is even breathing. Within the soothing/contentment system there is room for others and their desires and reason is functioning properly.

Within the field of the operator it is important during an incident that the contentment system can be utilized. When, on the other hand, the threat/self-protection system is activated, all symptoms that result from this system stand in the way of functioning effectively. It is aimed at self-preservation and not at helping others.

The importance of conscious attention

The exercises and techniques we use to teach the operator awareness and attention originate from Mindfulness. Mindfulness is the awareness that comes from purposefully giving attention to things as they are, in the moment and without judgment. Jon Kabat-Zinn (1991) has done much scientific research into the effects of meditation and Mindfulness and is the developer of MBSR/MBCT training, a series of techniques that teaches people to handle stress, fear, pain and illness.

PRACTICAL TRAINING MODULE: STRESS AWARENESS

To make operators aware of their own stress and tension and the effect of that tension on their functioning capabilities, we have developed a series of exercises. The mechanisms that can occur during an incident are purposefully triggered in a simulated setting. These are discussed, analyzed and experienced once more. This provides insight into the conscious behavior.

In the exercise we ask the participants to focus on their own breathing, muscle tension and thoughts. This is a first introduction to one’s own physical reactions in cases of tension.

Next, the participants are placed apart from each other in the room. A simulation actor performs the same exercise with each participant. He stands behind the participant and approaches them, then he stands next to the participant, and finally he stands in front of the participant and approaches them from there. There is no physical contact and there is no talking during the exercise.

After this first round, we discuss what the participant has experienced and what the actor and trainer have noticed. Each time, we discuss what the participant experienced in regards to breathing, muscle tension and thoughts. Based on the experiences, the participant is given a piece of advice to use in the next round. This advice can concern breathing, muscle tension or thoughts. An example of such advice is: “be aware of your breathing and make sure it remains slow”.

Next, we do an exercise and provide advice about becoming aware of your own breathing. Then we do the same exercises again and the participants are given the opportunity to apply the advice they have been given.

In a following exercise we consciously trigger the fight-or-flight-or-fright response, thereby providing an insight into its effect on one’s functioning.

After these exercises, operators often indicate that the exercise makes them aware of the effects of being fully present. They start to experience when tension is noticeable and become aware of the mechanism of fight, flight or freeze and experience the influence they have on their own thoughts and breathing and
their ability to control them. They start acting more aware.

THE RESULTS OF STRESS AWARENESS EXERCISES FOR OPERATORS

Relaxation
Stress awareness exercises lead to relaxation in the long term (Benson, 2000). Heart rate, oxygen use and blood lactate values (a chemical substance that, when found in high concentrations, is associated with fear, and, in low concentrations, with rest and relaxation) dropped during meditation. Long-lasting stress has a negative influence on physical and mental health that can cause lack of motivation, sick leave and even burn-out.

On the short term the benefit for the operator is that the relaxed state means that the operator is able to start the incident at a lower stress level enabling him to focus on his tasks more effectively. The operator recognizes rising stress levels and can respond adequately.

Thoughts
We experience about 40,000 thoughts per day. Luckily, we are not aware of each of those thoughts, but they do influence and subconsciously guide us throughout the day. Thoughts can be helpful or unhelpful. This determines whether tension increases or not. Giving guidance can prevent tension from building. For the operator this competence is valuable in two ways. The operator has a standardized job. When everything goes well, those thoughts can direct him away from his primary tasks. Being aware of this process allows the operator consciously focus on his tasks. When an incident happens a lot of tasks have to happen in a short period of time and a lot of information is send to the operator and create thoughts and actions that can lead to tension. Preventing tension to rise allows the operator to stay in control.

Acceptation
No matter how well-trained operators are, how elaborate the procedures are and no matter how many difficult situations they have been through, there are always incidents and calamities that are new and different to them. Understanding how your body reacts in such an event helps the operator in controlling his reaction. Being aware that these stressful unexpected events can happen helps the operator to stay focused. Accepting that road users and operators or other first responders sometimes will act unexpectedly allows them to act flexible and sometimes deviate from the standard procedures when it is best to support the self-rescue phase or other phases related to incident management. Evaluating the deviations help in improving procedures.

Compassion
Stress awareness helps you focus your attention. Receiving attention gives one the feeling of being understood. Also, we often know immediately when someone is not paying attention and is occupied with something else. By focusing our attention we focus on the other person (The road user) , thereby making them feel taken serious and understood . The road user will then be more inclined to have that same attitude towards you, and will be more likely to follow instructions. Adding focused attention will increase the effectiveness of the communication. Understanding that road users can also face a primary impulse responses helps for better understanding.

Insight provides choice
Stress awareness gives insight into coping strategies and the operator’s own preferred strategy. A coping strategy is the way in which one deals with stress and problems. Through stress awareness exercises insight is gained into one’s own coping strategy. Through observation of internal processes, feedback from observers and advice, operators can practice developing a more effective strategy.
meditation has been proven to have effected structural changes in the medial prefrontal cortex (Siegel, 2007). This means that one develops a larger range of coping strategies and is able to choose more quickly. For the operator this means that he can quicker understand his behavior and decide to change to the contentment strategy.

CONCLUSION

Over the last few years, enormous progress has been made in the prevention and containment of incidents and calamities. After the serious disasters in the tunnels in the Alps, a lot has been improved. Many adjustments and improvements concerning the revision of procedures and protocols have been implemented. The neurophysiological process which occurs with both the operator and the road user (that causes stress) can now be incorporated in the education, training and exercise programs of operators. These exercises determine whether an operator is able to function or not. The insight into the stress mechanism and the functioning of our emergency system is the missing link in the process to reach maximum safety.

Awareness exercises help operators develop techniques to become more aware and present. This alertness makes it possible for the operator to make a rational decision, thereby providing the greatest chance of an effective response. This is in addition to improvements in procedures and protocols that resulted from previous research. Up until now, no investments have been made into the awareness of the mechanisms that occur when an incident takes place. The insight that neurophysiology provides us with, opens a range of possibilities for operators to more effectively act during an incident.

Acknowledging neurophysiological processes helps the operator in finding a successful coping strategy for stressful situations where it is necessary to deviate from procedures and protocols. Making sure that an operator can quickly appeal to his soothing/contentment system and is aware of the consequences of the threat/self-protection system, can prevent a lot of casualties. Actively training for this reduces costs and casualties on the short term. An additional long term advantage is the prevention of burnout and posttraumatic stress disorder.

The stress awareness module is recently successfully used in the Education, Training and Exercise program for operators in the Netherlands. During this program operators gain insight in the technical tunnel system, the procedures and organizational aspects to operate and maintain a tunnel and their specific role that connects the technical and procedural systems together. In continuation courses we go deeper into the material and repeat the exercises. Apart from that, we also discuss and analyze tension awareness and the experienced primary reactions during Virtual Reality and Mono- and multidisciplinary exercises. Stress awareness has become a third pillar on which the education program is founded.

RECOMMENDATION

1. Include a regular training module in your Training programme aimed at the awareness of internal processes during stress and create insight into one’s own primary reactions.
2. Provide techniques that help in employing more effective behavior.
3. Make it a learning objective for operators to be more relaxed and effective.
4. Include a ‘hot debrief’ session shortly after an incident. The operator is able to indicate how he experienced his internal fight-flight-freeze reaction and which system (threat/self-protection, incentive/resource-seeking or contentment) was first utilized.

Being aware of these physiological processes, the operator can act more effectively during an incident. This saves costs for the organization, reduces the unavailability of the asset and can save lives!
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Abstract

Safety is just one of the many aspects in infrastructure projects. Because safety is very broad it is often split up over different departments within the road agency. This paper tries to unify the safety principles and make recommendations towards an integral safety management plan that helps the road agency to manage safety in planning, design, construction and operational phase of the asset.

An integral safety approach looks at all the different aspects of safety such as, construction- technical-, worker-, fire-social-, environmental- and traffic safety and (cyber) security. These aspects are compiled into a safety management plan and become a work method and form a subset of the project management plan. A large part of this work method are the soft skills required during planning and design phases to envision the operational phase of the asset. The balance between mitigating safety risks in design and construction versus accepting risks and thus transferring safety risks to the community can be understood using a simple trade-off mechanism.

The importance of a unified work method regarding integral safety of the total project including the operations of the emergency response teams in the case of an incident will be visualized in a case study.

Introduction

Infrastructure projects usually are characterized by their large-scale, long term, considerable implementation risks and involvement of multiple stakeholders with different interests. There is technical, social and organizational complexity with many mutual and external dependencies and cross-links. Therefore a large number of projects in have to deal with major setbacks in costs, delays, technical difficulties and opposition from society.

These core problems are not only caused by the large-scale, construction risks and the involvement of various bodies in various stages of policy. Many problems arise in the way large projects are managed. In particular, the basic attitude to consider such a project as a technical realization, which is first prepared internally in detail and only then exposed to - often in a very defensive manner - political and social debate. This needlessly generates resistance and causes delay. The management of preparation, decision making and implementation deserve attention in an integrated manner at a much earlier stage. Together, the initiation, planning, design, implementation and completion phase form an integral approach in which choices for various aspects and interests in one phase immediately or at a later time will affect the outcome of the other phase.
Safety in projects

Safety is just one of the many aspects in infrastructure projects that plays an important role during the different project phases. Safety is characterized by a high degree of complexity. The distribution of safety responsibilities is not always clear and often not unequivocally defined. Safety responsibilities are strongly compartmentalised and fragmented. Therefore safety can become prone to political negotiation and decision-making, finding the right technical solution, balancing cost, interpretation of legislation and guidelines and perhaps mostly finding compromises between all parties concerned.

Safety consists of more than construction- or technical safety. Within projects also worker safety, fire safety, social security, object security, cyber security, traffic safety, safety for the environment and the actions of emergency services has to be taken into account in order to mitigate risks. Knowledge from various disciplines must be collected, processed, integrated and applied. This diversity of safety issues shows that safety is usually a subject where various departments and organizations are involved, with sometimes conflicting interests.

Because of the large scale of projects and the large number of parties involved, risks often do not receive timely or too one-sided focus in a project. The result is that risks remain underexposed and can only be addressed at a late stage, that important opportunities to take measures are missed, or that these measures only can be realized at high cost. There’s also a risk that emergency services, local residents and users of services have to deal with safety implications of decisions where they have had no influence on.

INTEGRAL SAFETY APPROACH

Safety in the broadest sense of the word must receive attention in the early stages of a project. In the initiation phase there are often made key decisions with respect to safety. It is therefore essential that all the parties involved reach a general consensus, so that no fundamental differences of interpretation arise in the next phases. The concept of integral safety is based on the approach of looking at safety risks from multiple angles with all the relevant parties involved from an early planning phase, with a focus on the entire lifecycle of the infrastructure to be constructed. By paying close attention to the various forms of safety and the needs of the parties, risks can be mitigated from the very first stages of a project. This will avoid major and costly modifications to be made in technology or organization and that the project will have to deal with setbacks in time, money and expectations.

The importance of looking systematically from multiple angles at safety during all phases we propose a three step improvement circle: First we start with a stakeholderanalysis, we then develop an outline safety concept in step 2. The results of the safety concept and the specifics are written down in an integral safety management plan. This plan forms the result and is an important communication tool with the stakeholders. During each transition in the development of the project these phases are repeated and finetuned. This continuous circle of improvement ensures that the safety management plan stays up to date and accurate.

Stakeholder analysis

With the development, design and construction of major infrastructure projects are many participants (stakeholders) involved: each with different roles and responsibilities for safety. Not only the design but also the usage phase largely determines the safety of the structure. It is therefore important that not only future management parties are involved but that users and emergency services are timely involved in development, planning and design. In that way interested parties can influence the level of safety from the very moment. In order to shape a balanced project an analysis of the various stakeholders is necessary. Essential to this approach is to bring together the different interests in a single integrated process under a central management. This way the contribution of all the different actors is part of the same context. A good stakeholder analysis and identifying their interests and requirements (key criterion) prevents all sorts of additional requirements at a later stage in the process, which can result in (unnecessary) problems.

Important note:
Not everyone involved in the project, has to play a role in the initiation stage. When too many people are involved the decision-making process can slow down and enthusiasm can fade away. Besides that, not all stakeholders are willing or able to actively participate in making safety arrangements.
Safety Concept

Often there is time lost because different stakeholders are thinking that they talk about the same thing, while later it turns out not to be. Therefore, at the start of the case study project stakeholders jointly formulate safety and security ambitions per theme. This forms the framework of common principles regarding safety and provides in addition to the legal and regulatory aspects the subjects that are also important within the project. Through an integrated conceptual and working framework there is clarity on the parties on the applicable safety approach and the safety results that have to be reached. With this shared vision motivated decisions can be taken regarding safety. It also will create support from within the project.

Integral Safety Management plan

In the process where various safety issues at different stages and a large number of parties are involved, process management is the key to successful results from planning to completion. After the joint safety ambition has been made various activities must be carried out to embed safety in the processes. The continuous safety management plan plays an important role.

The plan describes the shared vision of safety, process design, various security issues and the results of previous phases. The plan forms the framework for the various safety issues during the lifetime of the project, in which during the various phases motivated decisions regarding safety are taken. The management plan is intended to give all interested parties the assurance and confidence that:

- All safety aspects of a system are considered together.
- Nothing is forgotten.
- The project is licensable.
- The project is feasible.
- Safety can be justified afterwards.

The scope of the plan is the whole project, but the focus is always directed at the stage where the project is at that time. It is a phase document. In every phase of the project it will be updated.

CASE STUDY

The case study involves a complex infrastructure project in southern Belgium. On a relatively small area which is also used intensively by cars, public transport and other users the government realises a project that will significantly improve accessibility. Right in the historic city, a new ring road will be built that will relieve the surrounding roads and gives the city a better connection to neighbouring cities and provide easy access to the central train station. The construction of the new road is integrated in a large redevelopment project of a new and bigger railway station. The new station will have a bypass of 2 high speed rail tracks. A road tunnel under the train station with a closed length of approximately 755 meters is realized with two separate tunnel tubes (unidirectional) and two lanes in each direction. The tunnel is the main lifeline for the city and gives access to a large car park of 2000 vehicles. The tunnel also provides the kiss and ride access to the improved train station.

*Picture 1: birds view of the project*
This project chose an integral approach as the working method because of the various activities are linked due to the limited space and functional relationships. This decision was also made because there are three (future) management parties. The road agency, the rail agency and the private car park management entity.

Stakeholder Analysis

These parties have plans for their own separate objects, that fulfil the technical requirements of ‘stand alone’ objects. For example, the road tunnel complies with all road safety and tunnel safety regulations. These regulations do not take into account the relationships and interconnectivity of the escape routes of the underground parking facility to the road tunnel. The operators found out in the early stages of the project that their design plans and safety concepts do not automatically connect with the other parties. Through an extensive stakeholder management process all parties agreed to a common safety concept for their projects that is aimed at safety for the whole complex and not only per item or discipline.

Due to the various activities linked and functional relationships it was also necessary to identify the main stakeholders that could influence the project and their interest. The emergency services can influence the process leading towards rejecting or accepting the granting of the permit and where identified as an important stakeholder. In the case study the emergency services was represented by the police (traffic engineering) and firefighting service. The ambulance service was involved at a later stage. The stakeholder analysis showed that, because this is the first road tunnel in the area, they needed to be closely involved in the process leading of the level of technical facilities and procedures.

Safety concept

In the case study project, the joint ambition to maximum availability of the tunnel has led to a close relationship with the emergency services to develop technical solutions and organization procedures to minimize the number of full closures to a minimal, resulting also in good accessibility of the parking and train station. A keen sense for issues further away and looking broader than just the tunnel has revealed potential safety issues beyond the domain of the tunnel itself which contributed to getting the tunnel realized with a justifiable level of safety and within the limits of time and budget. Because the safety concept sets out the process and expectations clearly to all stakeholders right from the start of the project, it kept them closely attached to the process.

Safety management plan

The safety management plan in the case study let stakeholders operate in a proactive and transparent way. It prevent surprises, uncertainties and gave sufficient information while dealing with risks that could harm the whole project, during construction and during usage. Whenever there was a technical discussion regarding safety of the project the integral safety plan provided guidance in the direction of a suitable solution. The safety management plan helped to agree on the level of facilities installed within the boundaries of the agreed safety concept with clear and transparent
knowledge for making the right decisions. Furthermore, to assure all the safety issues where resolved in the design phase all the stakeholders tested and approved the design. This prevents costly and time-consuming changes during construction.

For example, in the case study project cooperation in the early stage, led to a joint elaboration of an emergency plan for the discovery of bombs. The city in which the tunnel is realized was heavily bombed in the second world war and the probability that bombs were found during excavation work is high. In a joint emergency plan is assured that all relevant stakeholders using interoperable procedures to ensure the safety of the citizen and workers and prevent delay in construction.

THE RESULTS
The approach whereby stakeholders are identified and participate from the initiation to the operations phase by means of a joint safety ambition and assurance through a comprehensive safety management plan has the following results:

- Integral safety is included from the first phase and therefore part of the choice alternatives and variants of the project.
- Safety risks are mitigated from the early stages of the project or accepted by all parties as residual risk
- Area-specific approach. The safety plans of multiple operators and agencies come together. The project does not look at safety of each individual object, but at the safety level as a whole.
- Participation and involvement of stakeholders from the initiation phase
- Public support for the project
- Involvement of licensing authorities, law enforcement and supervisors at an early stage is of great value. By investing a lot of time in the preliminary phase a lot of time saving has been achieved in the licensing stage time because the plan met all requirements.
- Attention to the demands of the different parties has led to robust plans. This reduces the risk of unforeseen (and additional) requirements related to ensuring the safety (building, user notification and opening).

CONCLUSION
The case of this major infrastructure project shows that an integrated approach will contribute to the early identification of safety problems, taking action and accepting residual risks that are considered socially acceptable by all stakeholders. From the standpoint of safety there seems to be important gains by having attention for safety in the decision-making process at the initiation phase of the project.

The joint safety ambitions create a working environment which helps to make motivated decisions regarding safety. The participation of stakeholders in the initiation stage prevents major and costly changes in technology or organization which result in setbacks in time, money and expectations.

Integral safety does not only mean attention to safety risks, but also enforcement of the attention for safety in the continuation of the process during development, design and construction. An integrated safety management plan where the safety ambitions and process are included plays an important role in guaranteeing safety during all processes and phases of the project and lead to a manageable and accepted safety risk in the operations phase.
**Paper Title:** Performance Evaluation of Micro surfacing method including added amount of Buton natural rock asphalt.

**Track:** Modified Materials and Pavement Systems

<table>
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<th>Country</th>
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**Keywords:** Buton natural asphalt, Cohesive test, Wet abrasion test, Wheel tracking test

**Abstract:**

This paper describes an experimental test result to recycle a Buton natural asphalt aggregate for Micro surfacing pavement. The Buton natural asphalt aggregate was produced after extracting natural asphalt. Micro surfacing performance was evaluated as function of various application ration of Buton asphalt aggregate. Micro-surfacing is by improving elimination and abrasion resistance of aggregates, in Korea has been used as a pavement preservation method. In order to evaluate a performance, the cohesion test, wet abrasion test, and wheel tracking test were adopted. We compared the performance as changed amount of Buton asphalt aggregate such as 0%, 2%, 4%, and 6%. We showed that the Buton asphalt was substituted for the asphalt aggregate to 6% expressed the best performance.
Performance Evaluation of Micro surfacing method including added amount of Buton Natural Rock Asphalt.

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1. INTRODUCTION

The road is an indispensable element and gives a big impact on civilization and industrial development as a means for moving the human and economic goods. However, there are a lot of cracks and deformations occurring in the road due to various factors such as increasing traffic volume, climate change and material properties etc. Asphalt concrete is composed of mineral aggregate adhered with a binder. Asphalt pavement has the property of aging and damage progresses by traffic load, weather and various of external factors. And taking into account various factors such as the need to develop a method that can be satisfied cost-effective and technically. (Kwang-Tae Lee 2012)

This micro-surfacing method is one of the pavement preservation methods and the modified asphalt emulsion was added to natural latex using an ultrathin pavement method. Also it is an eco-friendly pavement method. The purpose of this study is to investigate a usage of Buton Rock Asphalt for the micro-surfacing. The Buton Rock Asphalt may be recycled and become an economical material in pavement preservation method if the micro-surfacing’s performance is satisfied. In order to measure the micro-surfacing performance as function of usage of the Buton Rock Asphalt, three test methods were adopted such as cohesion test, wet abrasion test, and wheel tracking test. The usage of the Buton Rock Asphalt were changed 2%, 4%, 6% of weight of natural aggregate for micro-surfacing method. Based on limited this study, the micro-surfacing method using 6% Buton Rock Asphalt aggregate shows the best performance. It means that the Buton Rock Asphalt aggregate has a potential possibility for using the micro-surfacing method in the future.

2. THEORETICAL BACKGROUND

2-1. BUTON ROCK ASPHALT

Asphalt is manufactured from crude oil. It is well-known that crude oil originates from the remains of marine organism and vegetables matter deposited with mud and fragments of rock on the ocean bed. Bituminous materials or asphalt are extensively used for roadway construction, primarily because of their excellent binding characteristics and water proofing properties and relatively low cost.

Asphalt is a viscoelastic material with suitable mechanical/rheological properties for traditional paving and roofing applications because of their good cohesion properties to aggregates. Buton asphalt used in this study is hard of natural asphalt in Kabungka area. Buton rock asphalt is natural asphalt from Buton Island in Southeast Sulawesi province in Indonesia. Buton Island has been known as natural asphalt sources. Currently the properties was not known widely, and the need to optimize it for use in asphalt pavements. It contain a mineral substance and the content of this asphalt has a fewer properties. It is used paving, flooring materials, waterproof construction, and acid-proof construction. Figure 1, Table 1, Table 2, is information of Buton Rock Asphalt. (Bambang Ismanto Siswosoebroto 2005)
Table 1. Properties of Buton Rock asphalt, (Mohamed H, Ali 2011).

<table>
<thead>
<tr>
<th>Properties of Buton Rock asphalt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Improvement in Mix Stability</td>
</tr>
<tr>
<td>2. Increased Strain Performance at Low Temperatures</td>
</tr>
<tr>
<td>3. Reduction in Surface Breakup</td>
</tr>
<tr>
<td>4. Reduced Maintenance Costs</td>
</tr>
<tr>
<td>5. Improved Ease of Handling in Bad Weather Conditions</td>
</tr>
<tr>
<td>6. Increased Stability at High Temperatures</td>
</tr>
<tr>
<td>7. Reduced Cracking</td>
</tr>
<tr>
<td>8. Increased Resistance to Fatigue</td>
</tr>
<tr>
<td>9. Improved Skid-Resistance and Road Safety</td>
</tr>
<tr>
<td>10. Ability to be Mixed with Almost All Other Binders</td>
</tr>
</tbody>
</table>

Table 2. Gradation of Buton Rock Asphalt & Mineral Composition of Kabungka Asphalt, (Bambang Ismanto Siswosoebrotho 2005).

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percentage Passing Kabungka Buton Rock Asphalt</th>
<th>Chemical Matters</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>inch</td>
<td>mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No.4</td>
<td>4.76</td>
<td>CaCO₃</td>
<td>81.62 - 85.27</td>
</tr>
<tr>
<td>No.8</td>
<td>2.38</td>
<td>MgCO₃</td>
<td>1.98 - 2.25</td>
</tr>
<tr>
<td>No.30</td>
<td>0.595</td>
<td>CaSO₄</td>
<td>1.25 - 1.70</td>
</tr>
<tr>
<td>No.50</td>
<td>0.297</td>
<td>CaS</td>
<td>0.17 - 0.33</td>
</tr>
<tr>
<td>No.100</td>
<td>0.148</td>
<td>H₂O</td>
<td>1.30 - 2.16</td>
</tr>
<tr>
<td>No.200</td>
<td>0.074</td>
<td>SiO₂</td>
<td>6.95 - 8.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Al₂O₃ + Fe₂O₅</td>
<td>2.15 - 2.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LOI</td>
<td>0.83 - 1.12</td>
</tr>
</tbody>
</table>

2-2. MICRO-SURFACING METHOD

Sustained economic growth and increased traffic volume caused by the development of the automobile industry generates a variety of cracks on the road. Thus, more economical maintenance process is required for the protection and restoration of the existing pavement skid resistance. Micro-surfacing method is one of the preservation pavement method and it is ultrathin pavement method used emulsion asphalt was added to natural latex. And production and construction is performed at room temperature and the harmful gas emissions including CO₂ is a very small eco-friendly pavement method. The average public lifecycle is about 5–7 years. Therefore, Micro-Surfacing eco-friendly method of fast transportation openness, several economic advantages, such as lead is a very effective method that can be represented in preservation pavement method. (Suk-Keun, Rhee et al. 1997)
Table 3 General properties of micro-surfacing method, (Mohamed H, Ali 2011).

<table>
<thead>
<tr>
<th>Applications Purpose</th>
<th>Apply place</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Prevent oxidation of the asphalt binder.</td>
<td>- Place the required surface is aging complements.</td>
</tr>
<tr>
<td>- Suppress damage to pavement.</td>
<td>- Place the required increase in the skid resistance.</td>
</tr>
<tr>
<td>- Improvement skid resistance.</td>
<td>- Where pavement is required, such as thin bridge deck of the bridge.</td>
</tr>
<tr>
<td>- Abrasion prevention of the existing pavement.</td>
<td></td>
</tr>
<tr>
<td>- Prevent rainwater penetration.</td>
<td></td>
</tr>
</tbody>
</table>

**Micro-surfacing properties**
- The mixture is pushed or not is a phenomenon in which deformation occurs in summer.
- Improved skid resistance.
- Reflection cracking of the micro crack is suppressed significantly.

2-2-1. EMULSION

Emulsified asphalt is used in Micro surfacing is consist of asphalt, water, natural latex such as additives and it will make the asphalt to be used at room temperature without heating a particulate dispersed in water. The emulsion for Micro-surfacing is used a cationic emulsion by adding a polymer. Binding affinity, durability, cure speed, temperature of the reforming asphalt is controlled by the emulsifier to be used. And by the addition of the latex can increase the cohesion between the aggregate and the asphalt. Polymer is enhancing to liquidity of mixture by increasing the elasticity of the asphalt. Thermo-sensitivity is made a small mixture and is increased the cohesion of the aggregate. It has the property of reducing the loss due to wear of the elimination or the mixture of the aggregate. Table 4 is ingredient of emulsion. (Byung-chul, Seo 1991)

Table 4. Ingredient of Emulsion, (Byung Chul, Seo 1991).

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Composition ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt</td>
<td>60</td>
</tr>
<tr>
<td>Water</td>
<td>40</td>
</tr>
<tr>
<td>Emulsion</td>
<td>1.5</td>
</tr>
<tr>
<td>Acid</td>
<td>1.0~1.5</td>
</tr>
<tr>
<td>Polymer</td>
<td>more than 3.5</td>
</tr>
</tbody>
</table>

3. EXPERIMENTAL METHODS

Table 5 shows mix design for this study. As shown in Figure 5, an amount of the Buton Rock Asphalt was used for the micro-surfacing method. The adopted ratio was 0%, 2%, 4%, and 6% and the Buton Rock Asphalt aggregate was replaced natural aggregate in the micro-surfacing method.

Table 5. Mix Design.

<table>
<thead>
<tr>
<th>Aggregate (%)</th>
<th>Emulsion (%)</th>
<th>Water (%)</th>
<th>Cement (%)</th>
<th>Buton Rock asphalt substitution rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 - 5</td>
<td>12</td>
<td>8</td>
<td>1</td>
<td>0% ~ 12%</td>
</tr>
</tbody>
</table>
completed curing, pavement distress such as aggregate loss can be observed because of insufficient adhesive strength between aggregate and binder. Therefore, accurate cohesion measurement is very important in determining the safety and cost-effectiveness. (Kwang-Tae Lee 2012)

3-1-1. SAMPLE FABRICATION AND TEST METHOD

The aggregate which passed through by using the No. 4 sieve was prepared 300g for sample preparation. According to mix design as shown Table 5, cement, water, asphalt emulsion and Buton natural asphalt or natural aggregate is prepared by measuring the weight.

First, evenly mix the cement, aggregates, Buton rock asphalt in a prepared sample. Three samples are mixed for 30 seconds evenly. The mixture is poured in the circular mold of diameter 60mm, height 6mm over paper, and samples are filled full of mold inside the circle using a spatula, and to keep the surface of the sample in a circular mold in a horizontal state, when the shape of mixture is not collapse, circular mold was removed vertically. The important thing is created from mixing to laid within 45 seconds, maintain don't solidify state have to produce a sample.

A specimen is removed from the mold at room temperature and cured for 30, 60, 90, and 150 minutes to measure. The minimum values required are 1.2 kilogram-meters for the 30 minutes test, 2 kg-m for 60 min. Figure 2 shows the modified cohesion tester used in this study. The 30-min modified cohesion test results is used to evaluate setting properties of micro-surfacing mixtures, while, the 60-min cohesion values can be considered as evaluation of traffic time (i.e., early rolling traffic time occurs at a torque level of 2 kg-m).

In this study, four identical specimens of each micro-surfacing formulation were mixed and casted in 10 mm x 60 mm diameters ring mold centered on the roofing felt squares and allowed to cure at room temperature. Torque measurement was made at suitable time intervals such as 30, 60, 90, and 150 minutes after casting. Figure 2-a shows the cohesion tester, specimen and destructed specimen. (ISSA TB 139)

![Figure 2. Cohesion tester & Form of sample.](image)

3-2. WET ABRASION TEST

The wet abrasion test is used to determine the optimum asphalt content and the resistance of abrasion by measuring the amount of abrasion of the mixture of the samples in a wet state. This test is a test to measure the complex behavior of friction between the rubber and the wet sample and for the elimination of water, and loss. In this study, we evaluate the abrasion rate of the wet state in accordance with the mixing ratio when given the rotational friction between the rubber hose and a sample from the immersion conditions loss amount should be less than acceptable standards. (Kwang-Tae Lee 2012)

3-2-1. SAMPLE FABRICATION AND TEST METHOD

Sample was fabricated by asphalt emulsion, water, cement and Buton natural asphalt and natural aggregate. The mixture is fixed on a pallet in the sample diameter 27.9cm, 6mm in height it poured into a mold on a expands widely. Removing the mold after cured and to dry at 60 ± 3 °C in the oven for 24 hours. The sample was then soaked in the water for 1 hour at ambient temperature. Figure 3 shows the wet track abrasion machine, specimen and testing procedure. The wet abrasion test was conducted for 5 min. The specimen was removed from the pan and washed off debris with slow running water. The specimen was then placed in an oven at 60°C to dry to a constant weight, and allowed to reach temperature and weighted. The difference between this new weight and the weight in grams obtained from before placing the sample in 25°C water
bath was reported as the abrasion loss of the specimen. Wet track abrasion test were performed on 1-hour soaked sample to determine susceptibility to moisture exposure. (ISSA TB 100)

**3-3. WHEEL TRACKING TEST**

Wheel tracking test was conducted to evaluate the performance of compaction by measuring the stability and resistance to compression with the vertical displacement of the sample and determine the best asphalt content. The wheel tracking test has been used to simulate the behavior of the current asphalt pavement and evaluate the durability. This study was conducted at ambient temperature and measured a vertical displacement of up to 1000 times of wheel loading. (Masoud Robati 2013)

**3-3-1. SAMPLE FABRICATION AND TEST METHOD**

Aggregate passed through the sieve No.4, asphalt emulsion, water, cements and prepare Buton natural asphalt. As seen in Figure 4, the specimen was fabricated by laying the rectangular central mold (12.7mm * 50.8mm * 381mm) and removing the mold and curing under atmosphere for 24 hours, the sample was dried for 18 to 24 hours at 60 °C oven. After the sample is cooling for 2 hours at room temperature (25 ± 2 °C), Setting the sample in the testing machine and vertical displacement is measured from the surface to 1000 cycle a load of 56.7 kg. Figure 4 is wheel tracking test machine. (ISSA TB 109)

**4. TEST RESULTS**

Figure 5~Figure 7 shows the test result for the effect of usage of Buton Rock Asphalt. All the test method in this study is based on the ISSA and standards specification of ISSA was indicated by a red line in Figure 5 ~ Figure 7. Figure 5 is wet abrasion test’s graph and all four graphs looks a state that satisfied the standards red line. As increased amount of Buton Rock Asphalt contents, there is no significant different wet abrasion ratio. The result as shown in Figure 5 was an average of three specimens. Figure 6 is vertical displacement of wheel tracking test up to 1000 cycle. As seen in Figure 6, the vertical displacement was fluctuated as changed
the Buton Asphalt ratio. However, the most of test results were satisfied the ISSA criteria except 4% of Buton Asphalt. The displacement of 6% Buton asphalt shows the similar trend that of 0% of Buton asphalt. It indicates that it has proper resistance against vertical deformation under traffic loading.

Figure 7 explains the cohesion test result to investigate setting behavior. The 90min. cohesion value was considered as evaluation of traffic opening time (i.e. early rolling traffic time occurs at a torque level 24kg·cm). As seen in Figure 7, 0% and 2% didn’t satisfy criteria, 24kg·cm, However, 4% and 6% was satisfied ISSA criteria, It means that two types of samples have proper resistance of traffic rolling.

![Figure 5. Wet abrasion test’s result graph](image)

![Figure 6. The result of Wheel tracking test](image)

![Figure 7. The result of cohesion test](image)
5. CONCLUSIONS

The overall goal of this study was to investigate a possibility of Buton Rock Asphalt for micro-surfacing aggregate. This study was achieved the possibility of Buton Rock Asphalt for micro-surfacing aggregate based on limited experimental test results.

1. Wet abrasion test result was all satisfied despite of different Boton Rock Asphalt contents. It indicates that different Buton Rock Asphalt doesn’t affect wearing problem under wet condition.
2. Wheel tracking test result shows satisfaction of criteria of ISSA’s vertical displacement. However, lateral displacement has a problem of all samples.
3. Cohesion test was clearly different as changed amount of Buton Rock Asphalt. As increased Buton Rock Asphalt, the setting time is reduced based on increased cohesion value.

ACKNOWLEDGEMENT

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REFERENCES

EFFECTS OF LIME ON RESILIENT MODULUS PROPERTIES OF A CLAYEY SOIL

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KEYWORDS:
Subgrade, lime stabilization, resilient modulus, high plasticity clay, soil pulverization level

ABSTRACT:
Lime stabilized soils are being used in construction of pavements for years worldwide and the design usually incorporates California Bearing Ratio (CBR) or unconfined compression strength values. However, in recent years, resilient modulus has been an important parameter in mechanistic-empirical pavement design. In this context, resilient modulus tests on lime stabilized high plasticity clay were performed within the context of this study. Tests were carried out in laboratories of Turkish General Directorate of Highways. Unstabilized and 4% lime stabilized samples were tested after seven and twenty-eight days of curing. Since it is possible that different soil pulverization levels can be encountered in the field due to different construction procedures, soil used was pulverized in two different levels; 100% passing No. 4 sieve (fine pulverization) and 60% passing No. 4 sieve (coarse pulverization). The results revealed that resilient modulus of unstabilized and lime stabilized soils were affected by the stress state (confining stress and deviator stress), curing duration and soil pulverization level. Lime addition increased the resilient modulus values. However, the amount of increase depended considerably on soil pulverization level. For lime stabilized samples and coarse pulverization, curing increased the modulus values for high deviator stresses. This was probably due to the fact that longer curing time is probably needed for lime particles to reach clay particles in case of coarse soil pulverization. Therefore design of pavements should take into account these parameters, otherwise, performance of pavements with lime stabilized layers may not reach expected levels. These experiments have been carried out within the context of a joint venture project, which is being carried out between Istanbul University and Turkish General Directorate of Highways. The results bring novel contributions to the construction procedures for lime stabilized clayey soils and emphasizes the importance of achieving fine pulverization as best as possible in the field.
EFFECTS OF LIME ON RESILIENT MODULUS PROPERTIES OF A CLAYEY SOIL

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1 INTRODUCTION

Lime stabilization is one of the most frequently used soil improvement methods used in pavement construction. In case, readily available soils are not appropriate to be used in subgrade level, lime stabilization of the soils can be an economic and environmental friendly alternative. It is well known that, lime increases the mechanical properties of soils, however, the key to pozzolanic reactivity and stabilization is a reactive soil, a good mix design protocol, and reliable construction practices (www.lime.org). In this context, it is very important that laboratory achieved improvement levels can be obtained in the field. Recent studies have shown that soil pulverization level is a very important parameter in lime stabilization of soils. In case, soil gradations used in laboratory are not met in the field, lime stabilization may not be as effective as targeted. Another important point is that current pavement design protocols are based on mechanistic-empirical approaches where resilient modulus values for pavement materials are needed. Therefore dependency of resilient modulus behavior of lime stabilized soils to different parameters, such as; lime content, soil pulverization level, curing time, and environmental conditions are important issues.

The experiments presented in this paper have been carried out within the context of a joint venture project, which is being carried out between Istanbul University and Turkish General Directorate of Highways. This project aims to fulfill two important aspects. The first is to investigate the effect of lime on resilient modulus properties of high plasticity clays. Dependency of resilient modulus on stress states, different curing durations and soil pulverization levels are investigated in detail. Correlations between resilient modulus, elasticity modulus and CBR values are also sought. Effects of curing, freeze and thaw and wetting and drying cycles are also included within the context of the project. Microfabric analyses will be carried out. At the last stage of the project, multi-layered elastic analyses will be run using the parameters obtained in the experiments. A design procedure according to mechanistic–empirical pavement design approach will be prepared related to lime treated subgrades. The results of the study will also be used to prepare a handbook on resilient modulus testing of lime stabilized soils. It is believed that outputs obtained in this project will be a tool to increase the use of lime stabilization in pavement construction in Turkey.

In this paper, preliminary results obtained in this project will be presented and discussed. Tests were carried out in laboratories of Turkish General Directorate of Highways. In this context, resilient modulus measurements obtained from unstabilized and 4% lime stabilized soils are presented. Two different soil pulverization levels were used in preparation of the samples. Curing durations were 7 and 28 days respectively.

2 LITERATURE SURVEY

Lime can modify almost all fine-grained soils, but the most dramatic improvement occurs in clay soils of moderate to high plasticity. In the short term, calcium cations supplied by the hydrated lime replace the cations normally present on the surface of the clay mineral, promoted by the high pH environment of the lime-water system. Thus, the clay surface mineralogy is altered, producing the following benefits; plasticity reduction, reduction in moisture-holding capacity, swell reduction, improved mechanical properties. In the long term, soil stabilization occurs through a pozzolanic reaction. This reaction produces stable calcium silicate hydrates and calcium aluminate hydrates as the calcium from the lime reacts with the aluminates and silicates solubilized from the clay. (http://www.lime.org). Due to these pozzolanic reactions, substantial increases in strength and modulus values are achieved.
Soil pulverization level has been found to be an important parameter in stabilization of soils. In laboratory, the gradations used for determining the mixture design are usually fine; in other words, 100% passing No. 4 sieve. For this purpose the soil is pulverized to eliminate all the clods. However, in the field, larger gradations are usually encountered, especially when dealing with high plasticity clays because it is hard to eliminate the clay clods. Felt (1964) studied the effects of soil pulverization level in cement stabilization and their results showed that in case less than 80% passed No. 4 sieve, effectiveness of stabilization decreased. The results of Grimer and Ross (1957) were similar; coarser pulverization meant lower strength values. Bozbey and Garaisayev (2010) studied the effect of soil pulverization on mechanical properties of lime stabilized soils. Three different pulverization levels were studied. Fine pulverization (80-90% finer than No. 4) resulted in much higher strength values than coarse pulverization (100% finer than 25 mm and 40% finer than No. 4). Average level of pulverization resulted in moderate values. The results were similar for modulus values measured through unconfined compression testing. The results obtained by Tang et al. (2011) and Toohey and Mooney (2011) revealed similar results. Effects of soil pulverization on resilient modulus has not been studied before, however, it may be anticipated that, soil pulverization affects the resilient modulus values as well.

Elastic modulus is basic property of any paving or roadbed material. However for those materials, which are subject to significant permanent deformation under load, this property may not reflect the material’s behavior under load. Thus resilient modulus refers to the material’s stress-strain behavior under normal pavement loading conditions. The resilient modulus is the most commonly used parameter in pavement design. The guide for design of pavement structures (AASHTO 1993) and the mechanistic-empirical pavement design guide (NCHRP 2004) have been developed and recommended the use of resilient modulus of subgrade soils in pavements structural design and analysis. Resilient modulus of subgrade soil can be estimated by conducting resilient modulus tests on the representative soil samples. Resilient modulus for granular materials and stabilized materials can be determined according to AASHTO method T-307-99. The load applied during the test protocol mimics the load duration and magnitude applied in the field. This test requires a haversine-shaped loading waveform. The load cycle duration is 1 second that includes a 0.1 second load duration and a 0.9 second rest period. The repeated axial load is applied on top of a cylindrical specimen under confining pressure and the total recoverable axial deformation response of the specimen under confining pressure. Total recoverable deformation response of the specimen is measured and used to calculate the resilient modulus. Resilient modulus is the ratio of deviator stress to total recoverable strain.

3 METHODOLOGY

Within the context of this study, effects of lime stabilization on resilient modulus values were investigated. Since different soil pulverization levels can be encountered in field applications, effects of pulverization level were also investigated. Soil brought from the field was pulverized at two different soil pulverization levels and then stabilized with 4% hydrated lime. Different curing durations; 7 and 28 days were applied. Resilient modulus tests were carried out after curing period was over. It should be recalled that additional lime percents and curing durations are also being tested within the context of the study, however, the experiments are still being carried out.

Physical properties of the soil used are listed in Table 1. The soil had a CBR value of 3 and very high swelling potential. Therefore the soil was not appropriate to be used in the subgrade level. Therefore stabilization with lime can be considered to be an alternative. In the experiments, a locally available hydrated lime was used. A photo of the soil in its original form is shown in Figure 1. Since it is a high plasticity clay, there existed a lot of clods of different diameters. This may reflect a typical gradation in the field, if enough consideration is not given during pulverization process.
Table 1. Index properties of the soil

<table>
<thead>
<tr>
<th>Measured property</th>
<th>Value</th>
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<tr>
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<td>Soil Classification, USCS</td>
<td>CH</td>
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<tr>
<td>Soaked CBR, %</td>
<td>3</td>
</tr>
<tr>
<td>Swelling in CBR, %</td>
<td>6</td>
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</table>

The soil was first air dried and then pulverized in two different pulverization levels. In “fine” soil pulverization level, the soil was pulverized so that all the soil passed through No. 4 sieve. In “coarse” pulverization, the soil was pulverized so that only 60%-65% of the soil passed through the No. 4 sieve. In all cases, the biggest clod was 20 mm. Before the resilient modulus samples were prepared, soil was air dried, necessary amount of hydrated lime by dry weight was added. In the last stage, water was added to increase the moisture content to optimum moisture content. The mixture was then wrapped with nylon sheet to prevent moisture loss and mellowed for one hour. The soil was then compacted in a special mold to prepare a resilient modulus sample of 10 cm diameter and 20 cm height. Standard Proctor Compaction was applied. The samples were then cured in a curing room for 7 and 28 days. After curing was over, resilient modulus tests were carried out. The details of testing procedure are given in Ozey and Gungor (2008).

4 RESULTS

In the resilient modulus tests, prior to actual modulus testing, specimens were conditioned to minimize the effects of improper contact between the specimen ends and the sample cap and base plate. After conditioning, soils were tested at three decreasing levels of confinement at five increasing levels of axial stress within each confinement stress level. Two samples were tested for each composition and curing durations.

In this study, tests were carried out at different deviator stresses, ranging from 14 kPa, 28 kPa, 42 kPa, 55 kPa and 69 Pa. Confining pressures used were 14, 28 and 42 kPa respectively. These stress levels are consistent with those confronted at the subgrade. The results of the tests are given in Figure 2 to Figure 5.

4.1. UNSTABILIZED SOIL (0% lime)

The results obtained for unstabilized soil (0% lime) are given in Figures 2 and 3. Resilient modulus values for unstabilized samples are important, because they are compared with those of lime stabilized samples to see the level of increased performance.

Figure 2 shows the results for 7 days curing for fine and coarse pulverization levels. In both pulverization levels, there was not a very strong dependency of resilient modulus values on confining stresses, however, when 42 kPa was applied as the confining stress, the values were slightly higher. Resilient modulus values ranged between 50 to 80 MPa for fine pulverization. However, for coarse pulverization, the values were much lower. The values were about 25 MPa for low deviator stresses and decreased to about 10 MPa for very high deviator stresses. The effect of deviator stresses on resilient modulus values was significant. Increased deviator stresses decreased the values considerably. As a result, the ratio of modulus values for fine to coarse pulverization was about 3 to 5. This is an important finding because it shows that soil pulverization level affected the modulus levels considerably even for unstabilized soils.

The results for 28 days curing are presented in Figure 3. For all samples, there was not significant difference for different confining stresses. However, for 42 kPa, slightly higher values were obtained. For fine pulverization, the values were again between 45-60 MPa for low deviator stresses and decreased to 35-50 for high deviator stresses. For coarse pulverization, the results were much lower as they were for 7 days curing. They ranged from 25 MPa to 10 MPa. For all samples, there was a decrease of values with increasing deviator stresses. Decrease in modulus values with increasing deviator stress for fine pulverization was not as significant as it was for coarse pulverization. Fine pulverization seems to result in a more stable structure, which is harder to soften. Since there was no moisture loss during curing, the values are similar with those for 7 days curing. It is anticipated that there should not be significant differences in resilient modulus of unstabilized samples with different curing conditions. Only for prolonged curing durations, effects of aging can be pronounced.
As a summary, for unstabilized soil, resilient modulus values depended strongly on soil pulverization level. For finer pulverization, the results were much higher than their coarse pulverization counterparts. The minimum resilient...
modulus value obtained was 10 MPa, which can be accepted as a lower bound for this soil taking into account all stress states, soil pulverization levels and curing days.

4.2. 4% LIME STABILIZED SOILS (4% lime)

In this section, results of 4% lime stabilized samples are presented in Figures 4 and 5. For 7 days curing, the resilient modulus values were found to increase with 4% lime stabilization compared to unstabilized counterparts for each pulverization level. For both pulverization levels, resilient modulus did not decrease with increasing deviator stress values. Nearly for all deviator stresses, confining stress of 42 kPa revealed somewhat higher resilient values. For fine pulverization, the values were as high as 250 MPa. On the other hand, the values obtained for coarse pulverization was 100 MPa as a maximum value. Therefore, soil pulverization level affected the results considerably.

![4% lime, 7 days curing, fine pulverization](image)

Figure 4. Resilient modulus values for 4% lime stabilization for 7 days curing

For 28 days, confining stresses affected the resilient values for both pulverization levels slightly. Increasing the deviator stresses did not decrease the modulus values. On the other hand, soil pulverization levels changed the values of resilient modulus. For fine pulverization, the values ranged between 75-200 MPa. For coarse pulverization, the values were between 50-100 MPa.

To summarize, it is clear that 4% lime stabilization changes resilient modulus-deviator stress behaviour of unstabilized high plasticity clay. Resilient values increased significantly with 4% lime stabilization. For unstabilized soils, increasing deviator stresses decreased the modulus values, however, for 4% lime stabilization, this kind of softening behaviour was not observed.

4.3. COMPARISONS AND EVALUATIONS

In this section, some comparisons are made to clarify the differences. Figure 6 shows all samples for 7 days curing. The results are very interesting to show that, in case soil pulverization is not fine, 4% lime stabilization can not be beneficial. In other words, if soil is not fine pulverized before lime addition, the modulus values for 4% lime stabilization are very similar to those for unstabilized soil and fine soil pulverization.

![Figure 6](image)

Figure 6 shows all samples for 7 days curing.

Figure 7 shows the lime stabilized samples together for 28 days curing in Figure 7. After 28 days, fine pulveriation still resulted in higher values than coarse pulverization. This was valid for all deviator stresses. As an average, the ratio of modulus values obtained with fine pulverization and coarse pulverization is about 2. This is a big
difference in terms of performance. This meant that, the gap between the performances do not close after prolonged curing.

Figure 5. Resilient modulus values for 4% lime stabilization for 28 days curing

Figure 6. Comparison of Resilient modulus values for 7 days curing

Figure 7. Comparison of Resilient modulus values for 4% lime stabilization for 28 days curing
In Figure 8, effects of prolonged curing for coarse pulverization was investigated. As evident from the figure, prolonged curing increased the modulus values at higher deviator stresses. When compared with 7 days curing, resilient modulus remained high for high deviator stresses with 28 days curing. This may be explained by the possibility that coarse pulverization needed higher curing time as compared to fine pulverization. This is probably due to the fact that time is needed for lime to reach all the clay particles and form a stable structure.

![Figure 8. Comparison of Resilient modulus values for coarse pulverization for 7 and 28 days curing](image)

5 CONCLUSIONS

This study presents the preliminary results obtained in a project carried out to determine the effects of lime on resilient modulus values on a high plasticity clay. Lime increased the resilient values considerably. The level of improvement depended on soil pulverization level significantly. Stress state and curing time were also very important parameters.

It is clear that lime stabilization can be used to enhance the engineering properties of high plasticity clays. This will certainly increase the pavement performance and it be considered as a valuable tool in terms of economic and environmental issues. However, the results presented in this study show that the level of improvement depends on the curing time, stress state in the pavement and soil pulverization level considerably. Therefore design of pavements should take into account these parameters, otherwise, performance of pavements with lime stabilized layers may not reach expected levels.

It should also be recalled that resilient modulus is not only important parameter in pavement design. Strength, durability during freeze and thaw, wetting and drying cycles are important factors which should be examined. Experiments are being carried out within the context of our project to determine these effects and to bring a comprehensive look into the behaviour of lime stabilized clays.

ACKNOWLEDGEMENTS

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https://lime.org/documents


Evaluation of the Field Application of Glass-Fiber Reinforced Asphalt Mixtures and Early-Age Performance Monitoring

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**Keywords:**
Glass-Fiber, Hot-mix Asphalt, Pavement, Fiber-Reinforced Asphalt

**Abstract:**
This study aims to develop paving material that can prevent the potholes on the road pavement by improving the durability of the asphalt mixture. Using the glass powder aggregate made from the industrial by-product glass fiber to substitute the stone powder and the glass fiber, the field applicability of the glass fiber reinforced mixture, which was tested in a laboratorial setting, was evaluated. Through indoor mix design, the optimal amount of reinforcement fiber was decided, and the field application was carried out after deciding optimal production temperature and number of compaction of the glass-fiber reinforced asphalt mixture. Furthermore, an indoor experiment on mechanical properties of the hot-asphalt mixture and glass fiber reinforced asphalt mixture produced in the field was carried out, as well as a follow-up study to evaluate the early performance of the mixture.
Evaluation of the Field Application of Glass-Fiber Reinforced Asphalt Mixtures and Early-Age Performance Monitoring

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1. INTRODUCTION

Recently, there is an increasing damage to the asphalt pavement such as pothole with an increase in heavy vehicle traffic on the road pavements with a high water penetration. These potholes are becoming a serious obstacle to the road safety, and are causing frequent traffic accident; some suspect that the early damages to the roads are caused by the subpar material used to pave the roads. Despite the numerous methods of repairs being utilized to mend these potholes, they resurface at the same site, as the repair methods were inappropriate for the sites with the potholes, and due to frequent repairs, the maintenance costs are still increasing.

Accordingly, this study aims to develop a paving material that can prevent potholes in the pavement by improving the durability of the asphalt mixture. Using the stone powder substitute glass fiber scrap (PPGS: PolyPropylene-coated Glass Scrap) and the glass fiber (PPGF: PolyPropylene-coated Glass Fiber) that is made from the industrial byproduct glass fiber powder, the field applicability of the glass-fiber reinforced asphalt mixture, which was certified for indoor experiments, was evaluated. Through indoor mix design, the optimal amount of reinforcement fiber was decided, and the field application was carried out after deciding optimal production temperature and number of compaction of the glass fiber reinforced asphalt mixture. Test pavement was carried out at Route 38, which is within the jurisdiction of Suwon Construction Management Office, over two times, applied to 100m out of overall 500m section; in order to compare the field applicability, the mixture was produced with different amount of reinforcement fiber: 1st test pavement was carried out with 1.3% glass reinforcement fiber (long glass fiber pellet 0.66% + recycle pellet 0.66%) per volume of total mixture produced, and 2nd test pavement was carried out with 1.0% glass reinforcement fiber (long glass fiber pellet 0.5% + recycle pellet 0.5%) per volume of total mixture produced. In addition, an indoor experiment on mechanical properties of the hot-asphalt mixture and glass-fiber reinforced asphalt mixture produced in the field was carried out.

2. OUTLINE OF FIELD APPLICATION

Figure 1. Pavement condition at the field site
The road section within jurisdiction of Suwon Construction Management Office was in bad condition with cracking ratio 31.92% and rutting rate of 10.07mm and thus in need of repair, despite frequent repairs in the past.

2-1. SUMMARY OF TEST CONSTRUCTION SITE

Following figures 2-3 and tables 1-2 show experimental pavement sections and extensions, construction date, and construction material.

Table 1. Summary of 1st test construction site

| Test Pavement Section | Route 38 in Suwon Construction Management Office jurisdiction (Pyeongtaek Si, Gyeonggi Do) |
| Test Pavement Extension | Total 250m (two-lane section), Glass-fiber reinforced asphalt mixture pavement 50m |
| Test Construction Date | October 17th, 2014 |
| Test Construction Material | Dense gradation asphalt mixture + glass fiber (long glass fiber pellet(PPGF) 0.66%+ recycle pellet(PGPS) 0.66%) |

![Figure 2. Cross section of 1st test construction site](image)

Table 1. Summary of 2nd test construction site

| Test Pavement Section | Route 38 in Suwon Construction Management Office jurisdiction (Anseong Si, Gyeonggi Do) |
| Test Pavement Extension | Total 250m (two-lane section), Glass-fiber reinforced asphalt mixture pavement 50m |
| Test Construction Date | November 12th, 2014 |
| Test Construction Material | Dense gradation asphalt mixture + glass fiber (long glass fiber pellet(PPGF) 0.5%+ recycle pellet(PGPS) 0.5%) |

![Figure 3. Cross section of 2nd test construction site](image)

3. PRODUCTION PROCESS OF GLASS-FIBER REINFORCED ASPHALT MIXTURE

3-1. PRODUCTION PROCESS OF GLASS FIBER

The glass fiber that was used to reinforce the asphalt mixture was recycled from glass fiber powder to substitute the stone powder that is added when producing the asphalt mixture. The glass fibers used in this study were a chopped glass fiber rod containing 800 to 1,000 mono-filaments of glass fibers. The roved multifilament glass fiber was first coated by the PP resin through the impregnation process. Besides the physical characteristics, as shown in Table 1, the mechanical properties of the fibers, such as tensile strength and Young’s modulus are referred from the study of Wallenberger et al., are at least 100 times higher than the typical values of a HMA at room temperature (Wallenberger et al. 2001).

The density of glass fiber is relatively comparable to a general aggregate greater than 2.0 so that the
multifilament fiber rod may behave as an aggregate without any noticeable fiber’s balling during and after the dry and wet mixing process of HMA. The effective dispersion without fiber’s balling may be expected by the aggregate-like behavior of the fiber (Yoo, P.J. et al 2014).

Table 2. Physical characteristics of Glass Fibers

<table>
<thead>
<tr>
<th></th>
<th>Multifilament</th>
<th>Glass Fiber</th>
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<tr>
<td>Density (g/cm³)</td>
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<td></td>
</tr>
<tr>
<td>Elongation(%)</td>
<td>4.5-5.0</td>
<td></td>
</tr>
<tr>
<td>Number of Filament</td>
<td>800-1,000</td>
<td></td>
</tr>
<tr>
<td>Length (mm)</td>
<td>10-12</td>
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</table>

4. TEST CONSTRUCTION SITE

Glass-fiber reinforced asphalt mixture was produced in a same process as general asphalt mixture, with an additional step of adding the two types of glass fiber developed as an additive when adding the aggregate. The fiber was added at the hot bin gate of asphalt batch plant production process and aggregate collection gate for job mix design verification.

Asphalt mixtures were produced at the temperature of approximately 180~190 °C, and mixed for approximately 90 seconds—dry mixing time of 45 seconds and wet mixing time of 45 seconds. In a general plant, the production time of asphalt mixture is 10 seconds of dry mix, 50 seconds of wet mix, and 6~7 seconds of release.
Construction of glass-fiber reinforced asphalt mixture was carried out by first cutting 5 cm of existing pavement, tack coating, spreading, and then compacting. When spreading the mixture, there was no aggregation of fibers at the surface.

Compaction of the mixture was carried out in the order of 1st, macadam; 2nd, tire; and 3rd, tandem roller, and the compaction was carried out 4 times at the 1st stage, 8 times at the 2nd stage, and 4 times at the 3rd stage. The compaction temperature was higher than 140 °C at 1st stage, than 120 °C at 2nd stage, and 60-100 °C at 3rd stage, and separate experiments, compaction density using GPR, compaction rate using thermo-graphic camera, were carried out for the study during construction.

After 3rd stage compaction was completed and the surface temperature was below 40 °C, the traffic development was implemented, and the spread glass-fiber reinforced asphalt mixture is as shown in figure 12.
5. INDOOR TESTING OF MECHANICAL PROPERTIES

This study tested the mechanical properties of 3 types of surface layer asphalt mixture (general asphalt mixture, 1st test-paved asphalt mixture, 2nd test-paved asphalt mixture) using the field produced asphalt mixtures. For each mixture, quality control tests established by the Ministry of Land, Transport and Maritime Affairs in January 2014, and the results were all satisfactory. In addition, the Indirect Tensile loading Test was carried out to the test specimen created with Marshall compaction of 75 times on both sides, using the general asphalt mixture sample (HMA) and glass-fiber mixture sample(GFRA).
6. FOLLOW-UP INSPECTION OF TEST CONSTRUCTION SITE

Approximately 6 months after paving, a follow-up inspection was carried out to evaluate the impact of the early thawing season and traffic on the pavement performance of the developed material after field application.

As shown in figures 17 and 18, the sections of 1st and 2nd test construction sites with glass-fiber reinforced pavements did not contain any damages, while in the case of the section on 2nd test construction site with general asphalt mixture pavement, a severe crack (of approximately 28m of length) was observed.

![Figure 17. Section with glass-fiber reinforced asphalt pavement (no damage)](image17)

![Figure 18. Section with general asphalt pavement (cracked)](image18)

7. CONCLUSION

In this study, the indoor experiments on the applicability of the glass-fiber reinforced asphalt mixture using the mixture collected from the field were carried out, and following conclusions were drawn.

Comparing the constructability, compared to the general asphalt mixture pavement, the glass-fiber reinforced asphalt mixture can be produced and paved through the same process of production and pavement, with an additional step in process of adding the glass fiber.

When long glass fiber and recycle pellets were mixed in appropriate ratio to produce the mixture, there were no balling phenomena, in which the fibers aggregate, and moreover, the Buckeye effect, in which the glass fiber separates into fine strands, was verified.

Using the fine glass fiber powder (recycle pellet) that is a by-product in producing the glass fiber reinforced mixture in the form of aggregate will contribute to economic feasibility by substituting the stone powder that is added to the asphalt mixture.

According to the indoor experimental results of the collected samples at the construction site, the IDT values were found to be 1.37MPa for the general mixture, and 1.41MPa for the glass-fiber reinforced mixture, and in the case of glass-fiber reinforced asphalt mixture, the value was found to be smaller than that measured in the lab before the field application. This is considered to be due to the difference in the mixture produced at the optimal conditions in the laboratory, and the mixture produced at the asphalt mixture production plant at the construction site, and in order to minimize the difference, a strict quality control will be needed when producing the mixture at the construction sites.
According to the follow-up study carried out 6 months after the construction, compared to the general asphalt mixture pavement, there were no early cracks observed, and this result will be more visibly distinguished after the hot wet season that can affect the generation of potholes.

Through the field applicability of the glass fiber reinforced asphalt paving technique and the indoor experimental results obtained in this study, the glass fiber reinforced asphalt paving technique seems to be an environmentally friendly paving technique utilizing the recycled material that can tentatively replace the hot-asphalt paving. However, only a short-term evaluation of pavement condition, and not a continuous evaluation through a long-term follow up study, could be carried out due to the short performance period. Therefore, there should be a continuous inspection of pavement condition to understand the long-term damages, and modify and reinforce the paving technique accordingly.

ACKNOWLEDGEMENTS

This study was supported by the Internal Research Program (Pothole-Free Pavement System) of Korea Institute of Civil Engineering and Building Technology, funded by the Ministry of Science, ICT and Future Planning

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FHWA(Federal Highway Administration) (2005), Hot In-Place Asphalt Recycling Application Checklist, Pavement Preservation Checklist series.


### PAPER TITLE
Use of Impact Resonance Test for Determination of Optimum Rejuvenator Content for Recycled Asphalt Pavements

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### KEYWORDS:
Recycled Asphalt Pavements, Optimum Rejuvenator Content, Resonant Frequency, and Impact Resonance Test

### ABSTRACT:
Use of recycled asphalt pavement (RAP) for road construction is highly promoted due to major cost savings and environmental benefits. A challenge with using high percent of RAP in the asphalt mix is stiffening effect because of its highly aged asphalt binder. This concern has resulted in production of different rejuvenating agents by various manufacturers. Addition of rejuvenator to the aged asphalt increases its flexibility and reduces its cracking potential. The common methodology for determining the optimum amount of the rejuvenating agent requires mechanical and rheological tests performed on blends of extracted RAP binders, virgin binders and rejuvenating agents, followed by obtaining equivalent performance properties of the blends compared to that of the target binder properties. The process involved with this methodology is time consuming and expensive, with adverse environmental impact due to the use of chemical solvents. In the study presented here, a quick, simple, and non-destructive test methodology is suggested, as a novel approach, for determination of optimum rejuvenator content through mixture testing. Mixes prepared with RAP were blended with one type of rejuvenator at various contents and tested with the Impact Resonance Test. The tests were conducted at a range of temperatures to capture temperature dependent material properties such as Young’s modulus, Poisson’s ratio and damping ratio. It was shown that the test method possess the potential for determination of optimum rejuvenator content for RAP binders in a reliable and quick way. A nondestructive test methodology is suggested for determination of the optimum rejuvenator content, and recommendations are made for the next steps to complete the proposed concept.
Use of impact resonance test for determination of optimum rejuvenator content for recycled asphalt pavements

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1 INTRODUCTION

The emphasis on sustainable construction practices has attracted asphalt concrete producers to incorporate higher content of recycled asphalt pavement (RAP) material in road construction. However, the highly aged binder of RAP is a limiting factor for such usage as it adversely affects the pavement performance. Rejuvenating agents can be incorporated into asphalt concrete with high RAP content to restore the original properties of RAP binder to some extent. Addition of rejuvenating agents can improve the performance of asphalt concrete, yet the rejuvenating agent content must be properly selected to achieve the desired performance. Insufficient dosage will not deliver needed flexibility and overdosing can increase rutting susceptibility. The optimum content of rejuvenating agents can be determined from viscosity, penetration or performance based tests of binders at a range of temperatures. The most recent method of rejuvenator optimization is based on the Superpave grading system. In this method, mechanical and rheological tests are performed on the blends of extracted RAP binders, virgin binders and rejuvenating agents, with an attempt to reach a target binder grade. The testing involved with this process is time consuming and expensive. It also requires use of chemical solvents which is not desirable.

The problems associated with current techniques of rejuvenator optimization can be addressed through the use of non-destructive techniques of material characterization such as Impact Resonance (IR) test. The IR test has been used in asphalt concrete applications for several decades. It has successfully been implemented to monitor structural integrity of pavements, to detect changes in dynamic elastic modulus, and to construct master curve of asphalt concrete for material characterization (Whitmoyer & Kim 1994, Kim & Lee 1995, Daniel & Kim 2001, Kweon and Kim 2006, LaCroix et al. 2009, Ryden 2011). In recent publications (Boz & Solaimanian 2014 and 2015) by the present authors, the influence of specimen geometry and aspect ratio on the IR test was comprehensively investigated. Also, the authors implemented the IR test method in a novel and innovative way to determine the high temperature of RAP binders (Solaimanian & Boz 2014).

In the research presented here, versatility and power of the impact resonance test in determining optimum rejuvenator content is demonstrated. The method is applied to asphalt concrete mixes containing high percentage of RAP. In order to prove the concept, one type of rejuvenating agent was added into pure RAP material at various contents and the compacted specimens were tested at a range of temperatures with the IR test. It must be noted that in all the work presented in this paper, RAP was used as 100 percent, meaning there was no virgin binder or virgin aggregate introduced into the mix. It was deemed the most suitable approach to demonstrate the effectiveness of IR testing for the objective of this research.

1.1 Basics of Impact Resonance Testing

The equipment for IR testing and various modes of vibration are covered in numerous publications. The basic concept behind the test operation is determination of the amplitude and the rate of attenuation of induced vibrations and relating these parameters to the material properties. In principle, a specimen with free boundary conditions is slightly tapped with a rigid impulse tool at the impact location of interest to generate mechanical vibration. An accelerometer, connected to a data acquisition unit and mounted on the specimen at a location suitable for the test mode being evaluated, captures the resulting waveform vibrations from the short-term mechanical impact, and converts them into electric signals (Solaimanian & Boz 2014). The test can be conducted in flexural, longitudinal, or torsional modes of vibration.

Figure 1 shows testing configuration for one special case of flexural mode testing, as used for this research. Briefly; the disk shaped specimen, placed on sponge rubber mat, is excited at two locations, generating two flexural modes of vibration: one symmetric and the other antisymmetric. The accelerometer, mounted on the edge of the test specimen, senses the vibration. The captured data is in time domain and transformed into frequency domain data using Fast Fourier Transform (FFT) algorithm.
Figure 1. Impact resonance test set-up for flexural mode of vibration using disk shaped specimens.

Once the frequency domain is obtained, the frequency corresponding to the highest amplitude, known as the resonant frequency, is determined. In addition, from the data, the rate of decrease in vibration amplitude can be determined. The results, along with the specimen dimensions and mass, are used to determine modulus using equation 1 given in a publication by Martineck (Martineck 1965).

\[
E = \frac{48\pi^2 f_2^2 R^4 p(1-v^2)}{\mu^2 T^2}
\]  

(1)

where \( E \) is Young’s Modulus, \( f_2 \) is the flexural mode of vibration in symmetric mode, \( R \) is the radius of the specimen, \( p \) is the density of the specimen, \( v \) is Poisson’s ratio calculated as a function of \( T/R \) and \( f_2/f_1 \), \( \mu \) is a value measured as a function of \( T/R \) and \( v \), \( T \) is the thickness of the specimen, and \( f_1 \) is the flexural mode of vibration in antisymmetric mode.

It is important to note that equation 1 utilizes undamped resonant frequency. The measured resonant frequency in asphalt concrete is damped resonant frequency. Damping measured from dissipation of energy due to vibration is converted to the undamped resonant frequency before applying the equations. Damping calculations are made using Half-power bandwidth and the details of the method can be found elsewhere (Boz & Solaimanian 2014). Neither do the equation 1 accounts for loss modulus. The loss modulus plays a significant role in characterizing asphalt concrete, especially at high temperatures. The procedure for loss modulus calculation is given in Kweon and Kim (2006) and was followed for this study.

2 EXPERIMENTAL PROGRAM

2.1 Material, Material Characterization and Specimen Preparation

The work consisted of one source of RAP material, one type of rejuvenating agent, and an asphalt binder with a performance grade of PG64-22. The gradation of processed RAP material (black rock) was designated as a 9.5 nominal maximum size. RAP asphalt content, determined through solvent centrifuge extraction was 4.7 percent. Rejuvenator agent used was heavy paraffinic distillate solvent extract.

In achieving the objective of the study, the rejuvenating agent was mixed into RAP material at 0.5, 0.75, 1.5, and 3 percent dosage levels by the weight of the RAP material. These dosages correspond to 9.5, 13.7, 24, and 38.8 percent by the weight of RAP binder, respectively. The mixing of rejuvenating agent with RAP was achieved as follows; RAP material was broken down into sieve fractions and then combined to a specific batch weight according to the black rock gradation. The batched RAP specimens were placed in a force-draft oven for 60 minutes at 150°C before mixing with the rejuvenating agent. The rejuvenating agent was also heated in the oven to 150°C in a sealed quart can. After 60 minutes of conditioning, the rejuvenating agent was blended with RAP for a minute in a mixing bucket. Following mixing, the specimens were conditioned at 150°C for additional one hour. The specimens were then compacted to the dimensions of 150 mm in diameter and 50.8 mm in height, using a Superpave Gyratory Compactor (SGC). Two replicates were fabricated for each dosage level. The bulk specific gravity of the compacted mixes was obtained from vacuum sealing method following AASHTO T331, and the maximum theoretical specific gravity of the specimens was determined in accordance with AASHTO T 209.
2.2 IR Testing for this Research

The experimental testing set-up and procedure described in Martincek (Martincek 1965) were followed in performing IR tests. Tests were conducted in both symmetric and anti-symmetric modes of flexural vibration at a range of temperatures. Target test temperatures were -10°C, 4°C, 25°C, and 40°C. Actual test temperatures varied from the target temperature within a range of ± 0.5°C. Each test included 5 impacts at the specimen edge and 5 impacts at the specimen center.

3 TEST RESULTS AND DISCUSSION

3.1 Gradation and Air Voids

The gradation of the RAP (black rock) is presented in Figure 2. It has a nominal maximum size of 9.5 mm with a very small amount of material passing #200 sieve. Average air void content of specimens is plotted against rejuvenator dosage level in Figure 3. The reduction in air void as the dosage level of rejuvenator increases is mostly the result of rejuvenator filling the void space since all specimens were compacted to the same height. Due to softening effect of the rejuvenators, a lower number of gyrations (i.e. lower compaction energy) was needed to achieve the same height as the amount of rejuvenator was increased.

![Figure 2. RAP “Black Rock” gradation.](image)

![Figure 3. Change of air void of specimens with respect to rejuvenator dosage.](image)
3.2 Results from Impact Resonance (IR) Test

3.2.1 Test Repeatability

The technique followed in IR testing of asphalt concrete specimens was highly repeatable delivering very low coefficient of variation (COV). This coefficient did not exceed 3.4% for all cases except for dosage levels of 1.5 and 3 percent at testing temperature of 40°C where COV of about 7 percent was obtained.

3.2.2 Effect of Temperature and Rejuvenator Dosage Rate

Figure 4 presents the IR resonant frequency as a function of temperature and dosage rate for both symmetric (center impact) and antisymmetric (edge impact) modes of vibration. In general, it can be clearly seen that increase in temperature and dosage rate result in lower stiffness and lower resonant frequency. As the air void of the specimen has a significant impact on its stiffness, the results presented in Figure 4 bears the air void effect.

![Figure 4. Anti-symmetric (left) and symmetric (right) modes of testing with no air void normalization.](image)

As shown in Figure 3, the specimens have different air void levels and this variation must be taken into consideration for reliable interpretation of data. In previous studies by the authors (Boz & Solaimanian 2014 and 2015) sensitivity of the IR results to air void variation has been established. Those established air-void frequency relationships were used to normalize the test results to the same air void level (i.e. 7% air void). The air void adjusted results are plotted in Figure 5. As indicated before, the damping measurements were carried out using Half-power bandwidth method, and the percent damping for each rejuvenator dosage level is presented in Figure 6 as a function of temperature for both flexural modes of vibration.

![Figure 5. Anti-symmetric (left) and symmetric (right) mode testing with air void normalization to 7%.](image)
3.2.3 Determination of Material Properties

As the focus of this paper has been demonstrating the power of impact resonant testing for mix rejuvenator optimization, the IR results are simply presented in the form of resonant frequency and damping. However, complete analysis of data for mix design purposes (not the focus of this paper) requires extending the IR data into material properties using equation 1. As an example, such analysis for one of the specimens is presented in Table 1.

Table 1. Example calculation of material properties for one of the specimens tested at 24.8°C

<table>
<thead>
<tr>
<th>Density, gr/mm³</th>
<th>0.0023</th>
<th>Poisson’s Ratio (based on ratio of (f_2/f_1) and T/R)</th>
<th>0.28</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius (R), mm</td>
<td>75</td>
<td>Constant (\lambda), (from tables in Martincek 1965)</td>
<td>6.208</td>
</tr>
<tr>
<td>Thickness (T), mm</td>
<td>50.4</td>
<td>Storage Modulus, MPa</td>
<td>14746</td>
</tr>
<tr>
<td>Resonant Frequency: (f_1) (Anti-symmetric), kHz</td>
<td>4.453</td>
<td>Phase Angle, degrees</td>
<td>9.4</td>
</tr>
<tr>
<td>Resonant Frequency: (f_2) (Symmetric), kHz</td>
<td>6.747</td>
<td>Dynamic Modulus, MPa</td>
<td>14,946</td>
</tr>
</tbody>
</table>

3.3 Proposed Methodology for Optimization of Rejuvenator Content

To exhibit how the IR testing could be utilized for mix optimization, first the basics of binder grade determination with RAP are presented followed by the proposed method.

3.3.1 Basics of Binder Grade Determination for Mix Design with RAP

Deciding the stiffness of the binder at low and high temperatures (i.e. performance grade of the binder) is among the first steps of mix design. In this regard, three scenarios are conceivable as presented in Table 2. The term stiffness in the table is used to present the grade of the binder. Out of the four variables indicated, three are always known, and one is unknown. A blending chart could be developed to find the unknown. Details of current practices for using blending charts for this purpose can be found elsewhere (McDaniel et al. 2000). Depending on the unknown, the graphs shown in Figure 7 could be followed to determine the unknown.

Table 2. Different scenarios for binder grade determination or RAP content determination

<table>
<thead>
<tr>
<th>Case</th>
<th>Final Stiffness of Binder (Blend)</th>
<th>Virgin Binder Stiffness</th>
<th>RAP Binder Stiffness</th>
<th>%RAP Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>(G^{(1)})</td>
<td>G</td>
<td>G</td>
<td>X(^{(2)})</td>
</tr>
<tr>
<td>II</td>
<td>X</td>
<td>G</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>III</td>
<td>G</td>
<td>X</td>
<td>G</td>
<td>G</td>
</tr>
</tbody>
</table>

(1) \(G\): Known (Given), (2) \(X\): Unknown
Incorporating a rejuvenator into the RAP mixture adds to the level of complexity as there is one more variable to consider. However, most often as rejuvenators are used in high percent RAP mixes, all variables in Table 2 are known, and the unknown is the amount of rejuvenator needed. For this case, the performance grade of RAP binder at different dosage levels of rejuvenator can be developed and an optimization graph such as that shown in Figure 8. Once the graph is developed, for a known stiffness of the blend, a known stiffness of virgin binder, and an established level of RAP content, the optimum dosage of rejuvenator is determined, as shown in Figure 8.

![Figure 7. Plots of different scenarios for binder grade or RAP content determination.](image)

![Figure 8. Optimization amount of rejuvenator through blending charts.](image)

3.3.2 Proposed Method of Optimization Using IR

The procedure discussed above for optimization of rejuvenator dosage level using binder stiffness (or binder grade) can be replaced by IR testing as a fast reliable testing. In IR testing, the binder stiffness graphs are replaced with mixture stiffness graphs, regardless of whether rejuvenator is used or not. RAP mixes at different dosage levels of rejuvenator, as discussed in this paper, are prepared and tested with IR. Mixes are also prepared with virgin binder and RAP aggregate extracted from the ignition oven, and tested with IR. The results are used to develop a graph such as that shown in Figure 8. The graphs could be reported in either IR resonant frequencies, or after conversion of frequencies to modulus or stiffness. With known desired final stiffness (or IR resonant frequency), and known percent of RAP, the optimum amount of rejuvenator is established.
A study was undertaken to assess the potential of the impact resonance (IR) test for determining the optimum dosage of rejuvenators in asphalt concrete mixes incorporating high percentage of reclaimed asphalt pavement (RAP) material. The tests were performed on the asphalt concrete specimens made with 100 percent RAP material at varying rejuvenator contents. A total of 8 specimens were fabricated using Superpave Gyratory Compactor and tested in temperature range of -10°C to 40°C. Flexural mode of vibration was used. The testing clearly exhibited the power of IR testing for such purpose. The resonant frequency was reduced as the rejuvenator dosage of increased. Based on the test results, a method was developed and proposed to establish the optimum dosage level of the rejuvenator.

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REFERENCES


KEYWORDS:
Treated rubber, Crumb rubber, Interaction mechanisms, Rubberized asphalt

ABSTRACT:
An experimental approach for quantifying the extent of pre-treatment on crumb rubber materials is provided. This method can be used to identify sufficiently pre-treated rubber materials in the laboratory before incorporating the modifier into the asphalt mixture. A raw untreated #30 mesh crumb rubber material was used in this study. The same crumb rubber material was treated by two different manufacturers (Source A, and Source B) and was used in the analyses. A PG58-28 asphalt binder was blended with the two pre-treated rubber and one untreated rubber materials by means of the wet process. Then, the rubber particles were filtered out of the asphalt binder after blending using a draining procedure. The experimental program included rotational viscosity ($\eta$) and dynamic shear modulus (|$G^*$|) on the base binder and the sampled CR modified binders (both rubberized and residual). Findings from this study suggest that one of the pre-treated rubber materials (Source B) was sufficiently treated as no change in viscosity measurements was observed in the rubberized binder as compared to the base virgin binder. On the other hand, pre-treated rubber from Source A showed clear interaction effects and a significant viscosity increase in the rubberized binder. The dynamic shear modulus tests confirmed the findings from the viscosity measurements. Mixture testing is needed to confirm the validity of the evaluation process proposed in this paper and to capture the complete effect of pre-treatment on crumb rubber modified asphalt blends.
A Method for Quantifying the Extent of Crumb Rubber Pre-treatment

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1 INTRODUCTION

Crumb rubber (CR) has been used as an additive in asphalt mixtures since the 1950s. Superior performance of CR modified asphalt pavements has been reported by numerous researchers (Carlson and Zhu 1999, Hicks et al. 1999, and Way 1999). Various modification processes can be employed using CR using three major methods described as: wet process (McDonald technology), dry process, and terminally blended methods.

The most common CR modification method is the wet process. In this method, CR is added to the asphalt liquid and is blended at elevated temperatures (160-220°C). This method utilizes 15 to 25% CR by weight of the binder. In the dry process, the CR material is used as a fine aggregate replacement and is directly added to the asphalt mixture. The terminally blended process is similar to the wet process, with the exception that only about 10 to 12% CR by weight of the asphalt binder is used. In addition, polymeric additives may be used to help the CR particles remain in suspension. While the wet process has been proven to have superior performance, special equipment and mixers are required to produce the modified material which leads to an increased cost of the asphalt binder. The dry process does not require any special mixing equipment and has a potentially higher recycling demand into asphalt pavements. But on the other hand, the limited success and inconsistent performance of this method has raised concerns among researchers. To overcome the issues in both the wet and dry processes, pre-treated CR modifiers have been developed. Pre-treated CR modification of asphalt blends is similar to the dry process. CR is directly added to the asphalt mixture and does not require special blending techniques or exposure to elevated temperatures.

Stroup-Gardiner, Chadbourn, and Newcomb (1996) investigated the effects of pre-treated CR modifier on the performance of asphalt mixtures using both laboratory fabricated specimens and field sections. The study found that mixtures incorporating pre-treated CR exhibited the highest ability to reduce thermal stresses when compared with control (unmodified) mixtures and mixtures modified using the dry process (untreated CR). This indicates a potential for reduced thermal cracking for the pre-treated CR mixtures.

In a study on the properties of pre-treated CR modified binders; Campillo (2014) found that pre-treated CR improved the temperature susceptibility of asphalt binders. It was also found that pre-treated rubber improved the high temperature, as well as intermediate temperature performance of binders when tested in the Dynamic Shear Rheometer (DSR). In addition, it was concluded that pre-treated CR improves the overall consistency of binders and improves the temperature susceptibility.

Despite the potential benefits and improved properties documented in the literature, a fundamental method of quantifying the extent of pre-treatment levels on CR has not yet been established. Establishing such methods will help identify sufficiently pre-treated CR materials in the laboratory before incorporating the modifier into asphalt mixtures.

2 OBJECTIVES

This paper is aimed at proposing a process for effectively quantifying the extent of CR pre-treatment and whether or not the pre-treatment technique has met the anticipated levels of modification. Once this process is established, this will provide a basis on which sufficiently pre-treated CR materials can be identified in the laboratory before incorporating the CR modifier to the asphalt blend.
3 ASPHALT-RUBBER INTERACTIONS

3.1 Wet Process

As mentioned earlier, the wet process utilizes 15 to 25% CR by weight of the binder and is pre-blended with the asphalt liquid at elevated temperatures. The main mechanism of interaction between the two materials is the diffusion of light asphalt components (aromatic oils and resins) into the CR particles at high temperatures causing them to swell into the polymer chains (Attia and Abdelrahman, 2009). Literature indicates that the presence of CR particles in asphalt binder leads to a stiffening effect at high temperatures (e.g., 76°C), and a softening effect at lower temperatures (e.g., 15°C). This can be partially explained through the rule of mixtures theory as illustrated schematically in Figure 1. When a soft inclusion is present in a stiff medium, the stiffness of the overall matrix will be less than that of the stiff medium. At relatively high temperatures (76°C), the binder is softer than the rubber particle, the stiffness of the CR modified binder is expected to be higher than that of the base binder (Figure 1a). Similarly, at low temperatures (15°C), the binder becomes stiffer than the rubber particle; therefore, the modified binder becomes softer than the base binder (Figure 1b). However, it should be noted that this stiffening and softening effect cannot solely be explained by the ‘presence’ of the rubber particles in the binder. The absorption of the light asphalt fractions into CR particles leaves the residual asphalt binder with a higher level of heavy components. In addition, as the rubber particles are mixed with the binder at high temperatures and allowed to interact, diffusion as well as chemical interactions occur and antioxidants are released from the rubber particles into the asphalt liquid. At the end, the rubber particle becomes a viscoelastic blend of rubber-asphalt- and light binder fractions.

3.2 Dry Process

In the dry process, approximately 3% of CR by weight of the total mixture is used as a fine aggregate replacement and is directly added to the asphalt mixture. No interaction between CR particles and asphalt cement is expected to take place at the interface between aggregates coated with asphalt binder and the rubber particles. In addition, the CR particles are expected to act as elastic inclusion in the voids between the aggregates. Figure 2 shows a schematic illustration of asphalt-rubber interaction mechanisms expected to take place in a dry process asphalt mixture.

3.3 Pre-treated Rubber

CR pre-treatment is done by mixing the rubber particles with low viscosity petroleum based products or aromatic oils compatible with the lighter asphalt fractions. The treatment oil is added to the rubber (percent by weight of CR) and the two materials are mixed together at 135°C until the rubber particles are fully mixed and no oils are remaining (Newcomb et al. 1994). This process is done at least 24 hours prior to using the CR modifier in the asphalt mixture.

The main goal of CR pre-treatment or surface modification is to enhance the compatibility of the rubber material with the modified binder matrix (Kocevski et al. 2012). In addition, CR pre-treatment blocks
the penetration of asphalt liquid into CR and prevents the rubber particles from absorbing the light fractions of asphalt binder during and after mixing. After completing the pre-treatment process, the material is incorporated into the asphalt mixture in a manner similar to that of the dry process. Limited interaction time between CR and the asphalt binder allows the rubber particles to maintain their physical shape and elastic performance in the voids between the aggregates. If the CR material is sufficiently pre-treated, this should be seen as a reduction of the viscosity increase observed in typical CR modified binders (Newcomb et al. 1994).

Figure 2. Schematic explanation of asphalt-rubber interaction in a dry process asphalt mixture.

4 MATERIALS AND METHODS

The asphalt binder used in this study was an unmodified PG58-28. The raw untreated CR material utilized was a 30-mesh material, produced using the ambient process. In addition, the same rubber material was pre-treated by two different manufacturers (Source A, and Source B) and used in the proceeding analyses.

Since CR pre-treatment blocks the penetration of asphalt liquid into the rubber particles, no interaction between the asphalt binder and the pre-treated CR particles is expected to take place after adding the rubber into the asphalt mixture. To quantify the extent of CR pre-treatment and interaction effects between the pre-treated CR and the asphalt liquid, an experimental approach is proposed.

Untreated CR modifier shows clear rheological and interaction (stiffening and softening) effects on asphalt binder (Jamrah, Kutay, and Varma 2015). This phenomenon is not expected to take place in pre-treated CR modified asphalt binders as the rubber particles have inherent light asphalt components absorbed during the treatment process. Hence, no interaction in the rubber-asphalt blend is expected.

To address the objectives of this study, asphalt binder was blended with 10% CR by means of the wet process at 190°C for a 30 minute interaction period at 750 rpm (rotation per minute) shearing speed. This process was applied on the untreated as well as pre-treated CR materials. Then, a method similar to the “Basket Drainage Method” (Airey et al. 2003) was utilized to separate the swollen rubber particles from the asphalt binder after blending. In this method, the CR modified binder was placed on a #100 sieve, then placed in an oven at a temperature of 155°C and the residual (drained) binder was collected on an aluminium pan. Samples of both the CR modified binders “Rubberized binder” and the drained binders “Residual binder” were collected for further testing. The rotational viscosity (ƞ) and dynamic shear modulus (|G*|) of the base binder and the sampled CR modified binders (both rubberized and residual) were used for this purpose.

4.1 Rotational Viscosity

As mentioned in the previous section, pre-treatment of CR blocks the penetration of the asphalt liquid into the rubber particles. Hence; sufficient levels of pre-treatment yield a CR-asphalt blend with a viscosity similar to that of the base binder. The ability of asphalt liquid to penetrate into CR particles is controlled by the osmotic pressure. Therefore, it is assumed that the asphalt liquid will produce a vapor
pressure that would force the petroleum based product used for pre-treatment into the rubber particles rather than allowing it to modify or contaminate the asphalt binder (Newcomb et al. 1994).

A Brookfield Rotational Viscometer (model RVDV-II+) was utilized for viscosity measurements of the base binder and the rubberized binders produced using the wet process. The rotational viscosity tests were conducted in accordance with AASHTO T316 “Standard Method of Test for Viscosity Determination of Asphalt Binder Using Rotational Viscometer” on two test replicates at 135°C, with a rotational speed of 20 rpm using a SC4-27 spindle. Figure 3 shows the viscosity of the base and rubberized binders. As shown, a substantial increase in viscosity is observed for the asphalt binder modified with untreated CR. As previously noted; this phenomenon is expected to take place and is a typical material behaviour. On the other hand, pre-treated rubber modifiers are not expected to exhibit the same behaviour. Pre-treated rubber binders exhibited two different behaviours. Modification of asphalt binder using pre-treated rubber from Source A produced a rubberized binder with a viscosity ratio of 2.07 to that of the base binder. This suggests an insufficient pre-treatment level. Such high viscosity increase indicates that either the oil used in the pre-treatment process was not suitable, or that low percentages (below optimum) of oil pre-treatment were used. On the other hand, asphalt binder modified by pre-treated rubber from Source B had an almost identical viscosity of that observed for the base asphalt binder. This indicates that the pre-treatment level used for this material was sufficient and that the oil used in the pre-treatment process did in fact block the penetration of lighter asphalt components into the CR particles.

![Figure 3. Viscosity of virgin and rubberized binders.](image-url)

Unlike the pre-treated rubber from Source B, the preceding observations suggest that if the pre-treated material from Source A is incorporated into the asphalt mixture without prior blending with asphalt binder (dry process), the rubber particles will interact with the binder and it will no longer be serving as an elastic aggregate in the voids between the aggregates. The fact that the two materials interact may have several potential negative effects on the performance of the asphalt mixture in the field. For example, while mixing the binder and aggregates, if insufficiently treated rubber is at the interface between the binder and aggregate, it may absorb the light fractions leaving the stiff and brittle binder at the interface. This can potentially create a brittle bond between the aggregate and the binder.

### 4.2 Dynamic Shear Modulus

To further quantify the extent of CR pre-treatment on the materials investigated in this study, the mechanisms of interaction between asphalt liquid and CR materials were further examined using the dynamic shear modulus (\(G^*\)) test performed on the base binder, rubberized binders, and residual (drained) binders at different temperatures. This helped capture the effect of interaction between the two materials on the final
asphalt-rubber blend and helped eliminate the concerns over the possible effects the presence of rubber particles may have on viscosity measurements.

The dynamic shear modulus (|G*|) tests were measured using a parallel plate geometry in accordance with AASHTO T315 “Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)”. Three test replicates were used to generate the data at 15, 46, and 76°C and a frequency of 10 Hz. The 25 mm plate geometry with 1 mm gap was used for |G*| measurements at 46 and 76°C. And the 8 mm plate geometry with 2 mm gap was used for measurements at 15°C.

Figure 4 shows the effects of different CR modifier types on the stiffness of the base asphalt binder. As shown in Figure 4a (for |G*| at 15°C), the rubberized binder for untreated rubber is significantly softer than the base binder, whereas the residual binder is significantly stiffer. This is an expected result for the raw untreated rubber material. As described in the previous section, untreated rubber absorbs the light fractions, leaving the residual binder with heavy, stiff fractions.

As for the pre-treated rubber blends; a clear interaction between the binder and rubber particles for Source A pre-treated rubber was observed from the significant differences in stiffness of the rubberized binder and residual binders. Figure 4b and Figure 4c also show the clear interaction effects of untreated and Source A pre-treated rubbers on the base asphalt binder. The rubberized binder is significantly stiffer than the base binder at higher temperatures (e.g. 46 and 76°C). On the other hand, no absorption of light fractions is observed for Source B pre-treated rubber. The rubberized and residual binders produced using Source B pre-treated material exhibit very similar behaviour and show insignificant differences in rheology. The two materials have statistically identical behaviour. This confirms that properly pre-treated rubber does not absorb the light fractions of the asphalt liquid when incorporated into the asphalt mixture.

It should however be noted that the residual binder of the pre-treated rubber produced by Source B exhibited lower |G*| values as compared to the base binder. This may be because of the release of the fluid used in the ‘treatment’ of the treated rubber into the binder.

Rheological testing of CR modified asphalt binders provides fundamental characterization of the material. But in order to capture the complete effect of pre-treatment on CR modified asphalt blends, mixture testing is needed to confirm the validity of the evaluation process proposed in this paper.

5 CONCLUSIONS

Based on the preceding analyses, the following conclusions are made:

• A substantial increase in viscosity is observed for the asphalt binder modified with untreated CR.
• Modification of asphalt binder using pre-treated rubber from Source A produced a rubberized binder with a viscosity ratio of 2.07 to that of the base binder. This suggests an insufficient pre-treatment level. Such high viscosity increase in pre-treated rubber blends indicates that either the oil used in the pre-treatment process was not suitable, or that low percentages of oil pre-treatment were used.
• Pre-treated rubber from Source B produced an asphalt binder that had an almost identical viscosity of that observed for the base asphalt binder. This indicates sufficient pre-treatment levels used for this material blocking the absorption of the light fractions from the binder.
• A clear interaction was observed between asphalt binder and pre-treated CR from Source A, as evidenced from the significant differences in stiffness of the rubberized binder and residual binders.
• Pre-treated CR from Source B showed insignificant differences in |G*| for the rubberized and residual (drained) binders suggesting that no interaction (i.e., light fraction absorption) took place during mixing the rubber material with asphalt liquid at a high temperature.
• Findings from the |G*| tests were consistent with the findings from the rotational viscosity measurements.
• Unlike the pre-treated CR produced by Source B, findings from the rheological tests suggest that incorporating pre-treated CR from Source A into the asphalt mixture in a manner similar to that
of the dry process may not provide the anticipated benefits of CR modifiers in terms of fatigue/low temperature cracking.

- Further testing is needed on asphalt mixtures to confirm the validity of the proposed process.

**Figure 4.** Effects of different CR treatment methods on asphalt-rubber interaction at (a) 15°C, (b) 46°C and (c) 76°C.

7 ACKNOWLEDGEMENTS

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REFERENCES

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KEYWORDS:
Warm Mix Asphalt, Foamed based asphalt technologies, Nozzle based foaming

ABSTRACT:
This paper presents a state-of-the-art-review on foamed based asphalt technologies, quality parameters of foamed bitumen, mixture designs and performances. Foamed based asphalt technologies are commonly classified into four as: i) nozzle-based methods, (ii) synthetic zeolite-based methods, (iii) indirect foaming via mixing hot aggregates with asphalt and wet fine aggregate, and (iv) shear-based mixing. Among these foaming technologies, this paper initially focuses on the nozzle-based technology, since it has the highest share in the construction industry and comparably lower cost than the other technologies. Secondly, the quality parameters of foamed bitumen are discussed with respect to recent advances in the research studies. In the utilization of nozzle-based technology, main concern is to develop an accurate laboratory/field testing protocol to measure the reduction in the height of the foamed binder over time in order to evaluate the dissipation curve of the foam. In this paper, three innovative test procedures are summarized: i) the asphalt foam collapse test, ii) the ultrasonic and laser based method, and iii) the digital photographic method. The evaluated dissipation curves are used to calculate various quality parameters of the foamed binders (i.e., expansion ratio, half-life, foam index, bubble size distribution, surface area index). Finally, the studies investigating the relation between the quality parameters of the foamed binder and pavement performance are synthesized. Recent findings revealed the need for the standards and specifications on Warm Mix Asphalt (WMA). Hence, it is suggested that the new standards are required to consider the quality parameters of foamed binder as well as the target pavement performance.
AN OVERVIEW OF FOAMED BASED WARM MIX ASPHALT AND RECENT DEVELOPMENTS

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1 INTRODUCTION

Warm Mix Asphalt (WMA) technologies are developed to significantly reduce the mixture viscosity to facilitate better coating of the aggregates, increase the workability of the loose mixtures and provide better compaction at lower temperatures. The first laboratory studies started with Aspha-min zeolite by Mitteldeutsche Hartstein-Industrie AG in 1995 and it continued with WAM foam by Shell Bitumen and Kolo Veidekke in Norway in 1996. In 1997, the first field trial was performed with Sasobit in Hamburg, Germany. The earliest WAM foam and Aspha-min zeolite pavements sections were built in Norway and Germany in 1999. Although the first trial sections were paved and majority of the technologies were developed in Europe, these technologies has gained more interest in USA in the last decade.

In 2002, National Asphalt Pavement Association (NAPA) organized a study tour to Denmark, Germany and Norway to investigate the following warm mix technologies: (i) Aspha-min, (ii) WAM foam, and (iii) Sasobit. The study tour by NAPA is followed by a research, which was initiated at National Center for Asphalt Technology (NCAT) and sponsored by NAPA, FHWA, Eurovia and Sasol in 2003 (Prowell et al. 2012). Interests in WMA technologies in the U.S. have significantly increased after the first field trials with Aspha-min in 2004 in Florida and North Carolina (D’Angelo et al. 2008) and continued with field trials in Florida, Indiana, Maryland, New Hampshire, Ohio and Texas in 2005. In 2007, AASHTO and FHWA organized a scan tour to Belgium, France, Germany and Norway. D’Angelo et al. (2008) reported that WMA performance in Europe is same or better than HMA. In 2008, it was documented that 32 U.S. states has WMA trial sections. Moreover, Texas DOT introduced the first WMA specification, which allows WMA to be used statewide. The number of states having trial sections and specifications drastically increased by the end of 2011, where 45 U.S. states had trial sections and 30 U.S. states had specifications. It was reported that all 50 states in U.S. conducted trial WMA sections by the end of 2011. FHWA reported that WMA usage was 19.2 millions of tons in 2009 and 47.6 million tons in 2010, which was equivalent to 13% of overall asphalt production (Prowell et al. 2012). The latest NAPA and FHWA reported that 106.4 million tons of WMA were produced in US in 2013, which is five times more than the stated amount in the first survey in 2009. This survey also stated that one third of all asphalt produced in U.S. market were produced utilizing warm-mix asphalt technologies (Hansen & Copeland 2014).

WMA technologies are basically grouped into three as: chemical additives/surfactants, foaming methods and non-foaming additives. In the US market, over 30 different WMA technologies are currently in use, whereas more methods are available worldwide (Prowell et al. 2012). Due to 2013 survey, nozzle based foaming has the highest share (87%) of the market and additives (including chemical-based, foaming-based and organic-based) account for only 13% of the market (Hansen and Copeland, 2014). Zaumanis (2010) stated that foam-based technologies cost comparably lower than the other methods. This finding is also supported in NCHRP report 779. Nozzle based foamed technologies are estimated to cost 0.08 $/ton, whereas the additive based methods cost approximately $2.00 to $3.50/ton (West et al. 2014.).

2 BENEFITS OF WMA USAGE

2.1 ENGINEERING ASPECTS

Several engineering benefits from the use of WMA technologies in asphalt pavement construction are discussed below:

i) Aging of WMA Binder: The binders are not exposed to elevated temperatures during the production and construction of WMA pavements as compared to traditional HMA. Therefore, the WMA mixtures are known
to be less susceptible to aging and cracking, which can also lead to longer pavement service life (Hossain et al. 2009, Rubio et al. 2012).

ii) Workability and Compactability of WMA pavements: WMA technologies reduce the overall binder viscosity, which improves the workability of asphalt mixtures at lower temperatures. Thus, the mixtures can be compacted with less number of roller passes to reach the targeted density (D’Angelo et al. 2008, Hossain et al. 2009). Stiff mixes (i.e., mixes with high percent of Reclaimed Asphalt Pavement (RAP) and Recycled Asphalt Shingles (RAS)) have generally compactability problems, which lead to lower in-place densities. In order to suppress the compaction densities to target levels, the compaction temperatures or efforts may be increased, which can result aggregate breakdowns and damage in the pavement, even during construction. Therefore, WMA technologies help in the compactability of the relatively stiff asphalt mixtures in conventional compaction temperatures (Prowell et al. 2012).

iii) Usage of Reclaimed Asphalt Shingle (RAS) and Reclaimed Asphalt Pavements (RAP) in WMA pavements: The use of Recycled Asphalt Shingles (RAS) in asphalt pavements has four major advantages: (i) high asphalt binder content, 20% to 30% by weight of the shingle, (ii) high grade frictional aggregate, (iii) fiberglass fibers that promote flexibility in the asphalt mixes and, (iv) lime dust that is a natural anti-strip for asphalt aggregates. RAS used in paving mixtures range from 3% to 5% by weight of HMA or WMA mixtures. Potentially, WMA technologies also allow the use of less virgin materials, by utilizing high percentage of RAP in asphalt mixtures at lower temperatures. The decreased aging of the binder due to lower WMA production temperatures helps in rejuvenating the RAP binder, particularly in regard to low-temperature cracking (D’Angelo et al. 2008). Therefore, WMA enables the incorporation of both RAP and RAS in many mixtures not possible with HMA. For instance, in St. Louis, Missouri, an off-ramp at the exit 249 interchange on Interstate 70 was constructed with RAP, RAS and WMA mix in 2010. The mixture was a 12.5 mm Superpave surface mix containing limestone and traprock plus 17% RAP and 3% RAS. (Jackson 2011). NCAT placed two full-depth 50% RAP sections with HMA and foamed WMA, and one control HMA section with no RAP to NCAT Pavement Test Track in 2009. After the application of 10 million equivalent standard axle loads (ESAL), the high RAP WMA section performed as well as the control. No cracking, excellent rut resistance and lower texture changes were observed in the high RAP WMA section as compared to HMA control section. The performance of as the high RAP WMA was as good as high RAP HMA section (West 2012). Similarly, Zhao et al. (2012) studied the performance of the WMA foamed mixtures with 30% RAP as compared to HMA with 0% and 30% RAP. It was concluded that WMA with high percentage of RAP exhibited higher rut resistance, better moisture damage resistance, and better fatigue performance.

iv) Cold Weather Paving: The paving season in colder regions can be extended by utilizing WMA technologies due to WMA’s ability to maintain workability at lower temperatures. However, the production temperatures of WMA at cold weather applications depend on the WMA technology, ambient conditions and haul distance (D’Angelo et al. 2008, Kristjansdottir 2006).

2.2 ENVIRONMENTAL ASPECTS

The gas emission of asphalt plants is equivalent to 0.5% of the total gas emission in US. Therefore, Environmental Project Agency (EPA) does not concern the asphalt plants as the major source of the air pollution. However, the environmentalists cannot ignore this amount. In 2001, the National Institute for Occupational Safety and Health (NIOSH) in USA published a hazard review on Health Effects of Occupational Exposure to Asphalt. Lange and Stroup-Gardiner (2007) showed that the asphalt plant emission is dependent on the plant temperature. It is reported that there is no emission measured below 80°C and emission is about 1 mg/h at approximately 150°C (Ruhl & Lindemeier 2006). On the other hand, the emission amount drastically increases above 180°C (D’Angelo et al. 2008). Hossain et al. (2009) stated that WMA plant emissions are about 30% to 98% of HMA plant emissions. Due to this fact, the reduction in the fumes and odor improves the working condition at the plant and at the construction sites (Newcomb 2007).

2.3 ECONOMICAL ASPECTS

The economical advantages of using WMA technologies include the reduced fuel usage, long haul distance, rapid compaction and early traffic opening. The operation temperatures of WMA mixtures are
generally lower than the HMA mixtures. For instance, a temperature reduction of 28°C in an average asphalt plant corresponds to about 11% fuel savings (Cervarich 2007). West et al. (2014) reported 1,100 Btu/°F/ton energy saving. As part of the NCHRP 9-47 project, it was reported that the fuel savings in different WMA field trials varies from 15.4% increase to 77% reduction. Prowell et al. (2009) reported the average fuel saving as 23% in WMA applications. D’Angelo et al. (2008) reported the burner fuel savings vary from 20% to 35%. In addition, Hossain et al. (2009) indicated that the overall energy consumption ranges from 20% to 75% between HMA and WMA based on the utilized technology. The rate of cooling of WMA mixes is lower than that of the conventional HMA. Therefore, the haul distance of the mixes can be longer as the cooling rate is reduced. Thus, the paving costs could be reduced with good management and design. Moreover, the road constructed or maintained by WMA can be opened to traffic faster than conventional HMA (Hurley and Prowell 2006). This is very promising especially for high maintenance roads and intersections and airports (Zaumanis 2010).

3 RECENT STUDIES ON WMA MIX DESIGN AND SPECIFICATIONS

WMA pavements are constructed at a wide range of layer thicknesses, under a wide variety of traffic levels, utilizing different aggregate skeletons such as dense graded, stone matrix, porous and mastic asphalt pavement. NAPA and FHWA formed WMA Technical Working Group (WMA TWG) in 2005 (Prowell et al. 2008). The group had representatives from FHWA, NAPA, NCAT, NIOSH, State Asphalt Pavement Associations (SAPA), American Association of State Highway and Transportation Officials (AASHTO) and the Hot Mix Asphalt Industry. Their mission was to evaluate and validate WMA technologies and foster the environmental concerns. The WMA TWG submitted three high priority research needs statements that were combined into two projects by the NCHRP on mix design practices and engineering properties, emissions, and field performance of WMA technologies.

The objective of NCHRP 09-43 was to develop a WMA mixture design and performance analysis procedure for a wide range of WMA technologies in the U.S. Therefore, a procedure similar to AASHTO R35 was developed for the design of dense graded WMA mixtures based on limited empirical data. In the following, the NCHRP Report 691 suggested that the compactability, moisture sensitivity and rutting resistance of WMA are significantly different than HMA and should be evaluated according to draft Appendix of AASHTO R35 for WMA (Bonaquist 2011). Then, NCHRP 09-47A (Field Performance of Performance of WMA Technologies) project compared the emissions measurements of warm mix asphalt (WMA) technologies and of traditional hot mix asphalt. Hence, The NCHRP Report 779 proved the reductions in greenhouse gases, when WMA is used (West et al., 2014). In an another study (NCHRP 09-49), the moisture susceptibility of WMA technologies (Evotherm. Sasobit and Foaming) was studied (Martin et al. 2014). In the most recent study, NCHRP 09-53 (Properties of Foamed Asphalt for Warm Mix Asphalt Applications) aimed to develop a laboratory testing method for measuring the workability and coatability of mix design, to investigate the sensitivity of different binder types and foaming water contents on the workability and coatability of foamed asphalt mixtures, and associate the workability and coatability of foamed WMA versus HMA. Currently, the latest research is on the investigation of compatibility of Recycled Asphalt Shingles in Asphalt Mixtures with WMA technologies (NCHRP 9-55) and this project will be completed in 2016.

Although these large-scale projects and many others have addressed some of the unknowns related with the use and performance of WMA technologies. There are still lots of unknowns and concerns. Besides, there is no admitted standard preparation, production, evaluation and lay down specifications on the WMA pavements. Therefore, studies are first focused in understanding the foam binder properties under various different conditions (i.e. temperature, technology etc.) and then continued with investigation of mixture design and performance. In the following sections, foamed based WMA technologies, foamed binder quality parameters, mixture design and performance are discussed.

4 FOAMED BASED WARM MIX ASPHALT

The method of WMA foaming, regardless of the utilized technology, is the intrusion of small amounts of water to hot binder. When the material cost and easiness of production are assessed, foamed-based technologies are more cost effective than the other technologies considering the long-term production (Bennert 2008, Middleton & Forfylow 2009). Previous research studies proved that there are various factors affecting the foamability of the binders, including but not limited to the chemical composition and the
process of crude oil, the modification method, viscosity, temperature, water content, quality of water, bubble size and gradation, defoaming agents, foam promoters and atmospheric conditions (Kutay & Ozturk 2012 Ozturk & Kutay 2014a, Ozturk & Kutay 2014b, Newcomb et al. 2015).

The major foam based technologies can be grouped into four classes: (i) nozzle-based methods, (ii) synthetic zeolite-based methods, (iii) indirect foaming via mixing hot aggregates with asphalt and wet fine aggregate, and (iv) shear-based mixing. Although this methods are gathered under foamed based technologies, they produce wide variability in the foamed binders due to different foaming conditions such as temperature, water content, asphalt absorption by aggregates, etc. Therefore, the performance of WMA pavements may vary because of the variation in the degree of coating, amount of trapped moisture, asphalt binder absorption of aggregates.

5 SYNTHETIC ZEOLITE BASED METHODS

WMA foaming additives, Advera by PQ Corporation and Aspha-min by Aspha-min GmbH are the most common synthetic zeolites (Prowell et al. 2008). They are composed of aluminosilicates and alkalimetals that hold about 20% crystallized water. The water is released by increasing the temperature above the boiling point of water. Thus, the released water creates the foam. It leads a slight increase in binder volume and reduces the binder viscosity as well as providing 6-7 hours workability period till the temperature drops below approximately 100°C (212°F). It was documented that the mixing and compaction temperatures of the WMA are approximately 30°C less than conventional HMA. However, foamed binders with these additives are prepared and added in different ways. Advera is added to the binder shortly prior to mixing with aggregates and generally added at 0.20% to 0.25% by weight of the total mix. Lower dosage of the additive is used as a compaction aid. On the contrary, higher dosage of the additive is used if the binder content of the mix exceeds 7% by weight of the total mix. However, Aspha-min is mixed with the aggregates and the binder at the same time and added about 0.30% by weight of the total mix.

6 INDIRECT FOAMING BASED METHODS

The most well known indirect foaming method through wet and hot aggregates are Low Emission Asphalt (LEA) by McConnaughay Technologies and Low Energy Asphalt (LEACO) by Lea-Co (Prowell et al. 2008). In LEA and LEACO technologies, coarse aggregates are initially heated to about 150°C, mixed with (unfoamed) binder along with a coating/adhesion additive. Then, cold wet fine aggregate containing approximately 3% to 4% water and recycled asphalt pavement (RAP) is added. While mixing, the moisture in the wet fine aggregate turns into steam and creates the foam.

7 SHEAR BASED MIXING METHODS

Accu-Shear is a shear-based method developed by Stansteel Asphalt Plant Products that applies mechanical shear to mix the water and/or WMA additives by a colloidal mill (Prowell et al. 2008). The binder is foamed dynamically by adjusting the rate of shear, which is assumed to increase the life of the foam. Typically, one gallon of water is used for one ton of mixture.

8 NOZZLE BASED FOAMING METHODS

The principle of nozzle based foaming is to inject air and water into hot binder through a spraying nozzle. The water is turned into steam at atmospheric pressure, creating moisture bubbles in the binder, and significantly decreasing the overall viscosity. This increased volume help in better aggregate coating, mixture workability and compaction at lower temperatures. Currently, there are numerous different field and laboratory nozzle based foaming techniques, in which nozzle designs are significantly different. Therefore, the foam quality parameters (discussed in the following section) for the same binder foamed under the same conditions significantly vary between the technologies (Newcomb et al. 2015).

9 FOAMED BINDER QUALITY PARAMETERS FOR WMA

Researcher introduced several parameters to evaluate the quality of foamed binders. The most
widely used parameters are known to be: expansion ratio (ER), half-life (HL) and Foam Index (FI). Additionally, Kutay and Ozturk (2014a) introduced two other critical parameters; bubble size distribution (BSD) and surface area index (SAI). Although these parameters are introduced recently, it takes significant attraction. In the recent NCHRP report 807, a standard called “Determining the Size Distribution and Surface Area of Binder Foam Bubbles During the Foaming Process” is prepared and proposed as a new AASHTO standard (Newcomb et al. 2015). The equations are given in Table 1 (The detailed derivations of these equations are available in Ozturk 2013). To calculate the parameters in Table 1, the foam dissipation curve with respect to time is needed. Recent research studies majorly focuses on developing an accurate and repeatable laboratory/field equipment and protocol to measure the reduction in the height of the foam binder over time in order to calculate the dissipation curve of the foam. Ozturk and Kutay (2014a) proposed Asphalt Foam Collapse Test (AFCT), which is an automated test protocol designed to measure the reduction in WMA foam height over time, as shown in Figure 1a. The major components of the test setup are a camera, a light source, a heat resistant floating bobber, two precision bearings bolted to two individual rods, fishing line, weights, and a stopper. This system was validated with two type of camera: an iPhone camera (Apple, Cupertino, California) and a high-speed industrial camera. The video capturing capabilities of the cameras were 30 frames per second (fps) and 400 fps, respectively. This study indicated that analyzing one frame per second is acceptable accuracy for determining the continuous dissipation curve of the foam. These results were also verified with X-ray microtomography (XRM) images in their research (Ozturk 2013).

Table 1: Equations of Foamed Binder Quality Parameters for WMA

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<th>Quality Parameters</th>
<th>Equation</th>
<th>Notations</th>
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<tr>
<td>ER</td>
<td>$ER = \frac{V^0}{V^F}$</td>
<td>$V^0$: overall foam volume at time $t=0$ $V^F$: final binder volume after all foam dissipates.</td>
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<td>HL</td>
<td>$HL = t_{(0.5(V^0-V^F)/V^F)}$</td>
<td>$t_{(0.5(V^0-V^F)/V^F)}$: time between the time at which the foamed binder reaches its maximum volume and the time it reaches to half of the maximum volume.</td>
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<tr>
<td>FI</td>
<td>$FI = \sum_{t=0}^{t_{BN=1}} 0.5(ER_t + ER_{t+1})(t_{t+1} - t_t)$</td>
<td>t: time $ER_t$: ER at time=t $ER_{t+1}$:ER at time=t+1</td>
</tr>
<tr>
<td>BSD</td>
<td>$D = \sqrt[\frac{18\mu V}{(\rho_f - \rho_b)g}}$</td>
<td>$D$: diameter of the bubble (m) $\mu$: dynamic viscosity of the fluid (kg/(m.s)) $\rho_f$: density of fluid (kg/m$^3$) $\rho_b$: density of bubble (kg/m$^3$)</td>
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<td></td>
<td>$v^t = \frac{\Delta t}{h^t - h^{t+\Delta t}}$</td>
<td>$v^t$: average velocity of the bubbles escaped at time t, $h^t$: the height of the foamed fluid $\Delta t$: time interval, $h^t$ and $h^{t+\Delta t}$ are $h^{t+\Delta t}$: the height of the foamed fluid at $t+\Delta t$</td>
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<td></td>
<td>$PBE^t = \frac{V_B^t - V_B^{t+\Delta t}}{V_B^{t+\Delta t}} \times 100$</td>
<td>$PBE^t$: percentage of bubbles escaped at time interval $\Delta t$ $V_B^t$: (initial) volume of the bubbles at $t=0$ $V_B^t$:volume of the bubbles at $t$ $V_B^{t+\Delta t}$: volume of the bubbles at $t+\Delta t$ $PPE^t$: percent passing at time t</td>
</tr>
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<td></td>
<td>$PP^t = 100 - \sum_{i=1}^{\infty} PBE^{t_i}$</td>
<td>$PP^t$: percent passing at time t $BSA = \sum_{t=0}^{\infty} \frac{6V_B^{t_i}}{D^{t_i}}$</td>
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<td></td>
<td>$BSA = \sum_{t=0}^{\infty} \frac{6V_B^{t_i}}{D^{t_i}}$</td>
<td>$BSA$: total surface area of all bubbles (in mm$^2$) in the foam at time = 0</td>
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<tr>
<td>SAI</td>
<td>$SAI = \frac{BSA}{\pi d(h^F + 0.5d)}$</td>
<td>d: diameter of the container $h^F$: final height of the binder after all the bubbles dissipate</td>
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597
In NCHRP report 807 (Newcomb et al. 2015), an ultrasonic and laser-based method is proposed to evaluate the expansion and dissipation of foams, as shown in Figure 1b. Additionally, a digital photographic method is developed to evaluate the size, gradation and surface area of the bubbles in the foamed asphalt. The ultrasonic sensor and laser-based sensor in the setup are both used for the distance measurement in between the sensor and binder surface. The ultrasonic sensor reflects the sound waves over 100 mm circular area, whereas the laser based sensor reflects the light over 1 mm circular area. Upon these methods, the authors suggested laser sensor, since the hardware and software requirements are minimum and the test is not interfered with the sides of the container and can directly measure the foam in the sampling container. In their study, the second method developed is image-based. The surface of foamed binder is captured periodically with a digital camera with a flash perpendicular placed over the test container. In both of the methods, the researchers suggested using 1-gallon containers for the laboratory tests and 5 gallon buckets for the field tests. Although AFCT and the procedures introduced in NCHRP Report 807 are not compared simultaneously (side by side), the report confirms that the foam tests run by using the same foaming machine (PTI) produced similar results.

The results revealed the significant difference between different laboratory foaming technologies under same conditions. Newcomb et al. (2015) used three different laboratory foaming devices in their studies. Although the foamers are capable of producing foamed asphalt, the variability within the machines are high even the evaluated optimum water contents are different from equipment to the other. Ozturk & Kutay (2014b) investigated the effects of water content and air pressure on the foamed binder. It was stated that air pressure has more influence on the quality parameters than the water content. ER increases with the increase of water content and air pressure, whereas HL and FI decrease. FI, BSD, and SAI are reported to be more precise because their calculation is based on the whole dissipation curve of the foamed binder. The bubble size distribution becomes coarser as the water content and air pressure increase. BSD can be directly related to coating of aggregates and workability of mixture.

Ozturk and Kutay (2014c) followed Draft Appendix of AASHTO R 35: Special Mixture Design Considerations and Methods for WMA for the performance evaluation of WMA samples in their study. Although this study was limited with one type of binder and one type of aggregate source and gradation, the authors initially assessed the quality of the foamed binder in various conditions. Then, the performance tests were run on WMA mixtures prepares with various foamed binders. The performance based experiment matrix covered various performance tests including compactability, coatability, rutting, fatigue cracking and moisture susceptibility. When the foamed quality parameters and the mixture performances were analyzed together, it was proven that there is a strong relation in between the foam binder quality and performance of pavement. The authors suggested that the optimum conditions for foaming (i.e., temperature, water content,
air pressure) should be determined based on the performance tests.

NCHRP report 807 (Newcomb et al. 2015) presented anticipated standard test methods for the performance related parameters of foamed asphalts and for the design of asphalt mixtures. In this study, several foaming methods including zeolites and nozzle-based were used to evaluate the coating of aggregates and workability of mixtures. One of the key findings of this research is the foaming parameters are significantly affected by the source, the refinery production date, crude oil slate, and polymer modification of the binders. Upon their research, they suggested some revisions to of AASHTO R 35; to add more details related to laboratory foaming units, two procedures for adding foamed binder to mixtures in the laboratory, modifications for mix preparation and evaluation for coatability and workability measurements and an identification method for the optimum amount of foaming water content.

West et al. (2014) studied the field performance of 14 WMA projects in US. 6 of these projects existed, whereas the rest were new project. It is concluded that rutting performance of WMA sections are same as HMA sections. Moisture damage was not observed in any test sections. In addition, the traffic load did not affect the density changes in WMA as compared to HMA sections. Similarly, HMA and WMA sections exhibit same amounts of cracking, surface texture, texture changes after 2 or more years of traffic. Due to the field experience and previous studies, it is clear that the WMA technologies are promising based on the economy, environment, and engineering points. In other words, if WMA pavement sections are designed properly, it is expected to have equivalent or better performance than HMA.

11 CONCLUSION

WMA applications have gained lots of interest in US in the last decade, although majority of WMA technologies are developed in Europe. Surprisingly, the applications are still very limited in Europe because of the conservative structure. According to the recent studies, the economical, environmental and structural advantages of WMA are significantly encouraging compared to HMA. In US, the recent studies mainly focuses on the development of an accurate test method to measure the dissipation of foam, which is precisely achieved and validated in the identified studies. However, these methods need to be well accepted as a standard procedure and added to specifications by Authorities. In addition, the findings of the performance tests indicate the importance of foam quality on the performance of the pavement. Therefore, the future standards should consider these findings. Thus, the future standards are suggested to include foam binder properties sections. In addition, in the light of previous studies, it is recommended to widen the future studies on various binder types, binder modification methods, recycle materials, aggregate gradations and type to broadly evaluate the effect of foaming.

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Concrete road with wastes incorporation processing plants

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**KEY WORDS:** Concrete, pavement, wastes, processing plants.

**ABSTRACT:**
Currently, to provide environmental and economic rehabilitation and construction of roads sustainability, reduce both energy cost and environmental impact.
One option for achieving this is resort to the use of waste materials in industrial processes generated by the construction of new works.
This paper presents a comparative study between a conventional concrete and concrete made with waste processing plants concrete, in order to assess its application in road construction.
Physical and mechanical characteristics of component materials were analyzed.
The described concretes were developed, keeping the water / cement ratio, correcting the grading of recycled material within the parameters set by current standards.
Was studied for various concretes unconfined compressive strengths, flexural and tensile diametral compression and comparatively analyzing the results statistically.
Finally, conclusions and recommendations for research prosecution were developed by test sections.
Concrete road with wastes incorporation processing plants

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1 INTRODUCTION

In Argentina, civil construction annually generates significant amounts of construction and demolition waste (CDW). In the Province of Entre Ríos particularly, the industrial manufacturing process, transportation and placement of concrete generates approximately 8% of CDW. (Bolla et al., 2005).

In this case, the CDW generated by the washing of mixers placed in the grounds of the concrete manufacturing plant were evaluated. Some of the material is collected untreated (UW) and some other is placed in natural settling pools where gravity filters the impurities of the material out. Then, it is sieved in order to remove any excess (TW). (Figures 1a and 1b).

The feasibility of reusing both of these materials as components of a new concrete pavement has been investigated.

Figure 1a. Untreated material deposit. (UW)  Figure 1b. Treated material deposit. (TW)
2 RESEARCH DEVELOPMENT

Samples of lab scale collections were taken; tests on the characterization of commercial and recycled materials were carried out following ASTM, IRAM (Argentine Institute of Normalization and Certification), and DNV (National Roads and Highways Bureau of Argentina) regulations.

Figure 2 shows the grading of fine materials (S) extracted from the Parana River and coarse commercial (CR) extracted from quarries in the Uruguay River.

It can be seen that the coarse aggregate size 10-20 has a portion of sand (SCR) which was added to the fine mix.

A 2.85 fineness module was obtained from the fine mix (SG+SF+SCR). The curve of the mix was determined by considering the grading of coarse aggregates; the fineness module obtained was of 7.02. Table 1 indicates the physical characteristics of each commercial material.

![Granulometric Curves of Commercial Aggregates](image)

**Table 1 Physical characteristics of commercial materials.**

<table>
<thead>
<tr>
<th>Type of Aggregate</th>
<th>Density S.S.S. (g/cm³)</th>
<th>Absorption (%)</th>
<th>Fineness module</th>
<th>Compacted Dry Weight (g/cm³)</th>
<th>Los Angeles Abrasion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR 10-30</td>
<td>2.640</td>
<td>0.93</td>
<td>7.52</td>
<td>1.590</td>
<td>19.6</td>
</tr>
<tr>
<td>CR 10-20</td>
<td>2.641</td>
<td>0.95</td>
<td>6.74</td>
<td>1.592</td>
<td>20.1</td>
</tr>
<tr>
<td>SF</td>
<td>2.644</td>
<td>1.20</td>
<td>1.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SG</td>
<td>2.640</td>
<td>1.10</td>
<td>3.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCR</td>
<td>2.635</td>
<td>1.00</td>
<td>3.19</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The coarse composition for the different pavement dosages was carried out taking into consideration the limit curves of the Centro de Investigación de los Reglamentos Nacionales de Seguridad para las Obras Civiles (CIRSOC 201/2005 Regulation).

The samples of recycled material were divided into fine and coarse. Figure 3 represents the grading of the recycled material and of the mixes. As a result of washing, an excess of fines in both materials can be seen, which exceeds the specification limits.
Table 2 shows the physical characteristics of the recycled materials.

<table>
<thead>
<tr>
<th>Type of Aggregate</th>
<th>Density S.S.S. (g/cm³)</th>
<th>Absorption (%)</th>
<th>Fineness module</th>
<th>Compacted Dry Weight (g/cm³)</th>
<th>Sieve 100 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse TW</td>
<td>2.565</td>
<td>0.94</td>
<td>7.36</td>
<td>1.697</td>
<td></td>
</tr>
<tr>
<td>Fine TW</td>
<td>2.473</td>
<td>2.37</td>
<td>2.25</td>
<td></td>
<td>4.4</td>
</tr>
<tr>
<td>Coarse UW</td>
<td>2.570</td>
<td>2.21</td>
<td>7.24</td>
<td>1.557</td>
<td></td>
</tr>
<tr>
<td>Fine UW</td>
<td>2.548</td>
<td>4.33</td>
<td>2.41</td>
<td></td>
<td>9.6</td>
</tr>
</tbody>
</table>

The aggregate commercial mix for the control concrete (C⁰c) was determined and a fineness module of 4.4 was obtained.

Mixes with both recycled materials plus the commercial corrective material (90% of recycled material, 5% CR 10-20 and 5% CR 10-30) were made, obtaining a group FM of 4.2 for C⁰uw and of 4.3 for C⁰tw.

The different concretes were dosed using the proof batch method, adapting it to the simultaneous usage conditions of commercial and recycled coarse aggregates. Due to a higher absorption of the recycled aggregate, especially for the untreated aggregates, they needed to be saturated before being used in order to maintain the mix’s workability.

Portland cement type CPC40 was used according to IRAM 50000 Regulation and public supply water plus flux additive which was incorporated to the mixing water in a proportion of 1% of the cement weight.

Mix design parameters:
Characteristic Resistance ($f'_c$): 25 Mpa.
Water cement ratio: 0.44;
Expected settling (As) measured with Abrams cone: 5 cm.

Cylindrical test specimens of 15x30 cm of each dosage were made. Their workability; density of the fresh and hard paste; simple medium to breaking compression resistance ($f'_cm$); characteristic resistance ($f'_c$); and resistance to traction by diametrical compression (fct) were determined after 28 days of curing in a fog room.

Prismatic test specimens of 15x15x75cm were made, which determined the bend module (fr) after 28 days.
3 RESULTS

Table 3 shows fresh and hard densities values and settlements, measured in the different types of batches.

<table>
<thead>
<tr>
<th>Type of Cº</th>
<th>Fd (kg/m³)</th>
<th>Hd (kg/m³)</th>
<th>As (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cºc</td>
<td>2,407</td>
<td>2,398</td>
<td>4.7</td>
</tr>
<tr>
<td>Cºtw</td>
<td>2,347</td>
<td>2,340</td>
<td>5.1</td>
</tr>
<tr>
<td>Cºuw</td>
<td>2,351</td>
<td>2,342</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Table 4 and Figure 4 indicate the $f_{cm}$ and $f_c$ values of the different concretes. It can be observed that Cºuw and Cºtw do not reach the Cºc resistances, the difference is greater for concretes with untreated coarse.

<table>
<thead>
<tr>
<th>Type of Cº</th>
<th>$f_{cm}$ (MPa)</th>
<th>$f_c$ (MPa)</th>
<th>Variation Coefficient</th>
<th>% of $f_{cm}$ variation as regards Cc</th>
<th>% of $f_c$ Variation as regards Cc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cºc</td>
<td>32.00</td>
<td>26.70</td>
<td>7.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cºtw</td>
<td>27.59</td>
<td>22.54</td>
<td>9.45</td>
<td>-13.8%</td>
<td>-15.6%</td>
</tr>
<tr>
<td>Cºuw</td>
<td>25.48</td>
<td>19.02</td>
<td>10.29</td>
<td>-20.4%</td>
<td>-28.8%</td>
</tr>
</tbody>
</table>

Table 5 and Figure 5 show $f_{ct}$ values obtained in the test, applying the expressions (1) and (2), (Leonhardt F. y Mönning E., 1985), with the tensions expressed in MPa. These expressions consider a ± 25% variation interval.

\[ f_{ct} = 0.15 \times (f_{cm} \times 11.8)^{1/2} \]  \hspace{1cm} (1)

\[ f_{ct} = 0.06 \times \sqrt{(f_{cm} \times 1.18)^{2/3}} \]  \hspace{1cm} (2)

It can be observed that Cºuw and Cºtw do not reach Cºc resistances, the difference is greater in concretes with untreated coarse.

The values of the tests are inside the range foreseen by the previously mentioned expressions. It can be observed that the negative variations answer to pavement with untreated coarse.
Table 5. Traction by diametric compression resistance of the different concretes.

<table>
<thead>
<tr>
<th>Type of Cº</th>
<th>fct (MPa)</th>
<th>Variation Coefficient CV (%)</th>
<th>Variation of fct as regards Cºc (%)</th>
<th>fct Formulates (1) (MPa)</th>
<th>Variation between fct and Formula (1) (%)</th>
<th>fct Formulates (2) (MPa)</th>
<th>Variation between fct and Formula (2) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cºc</td>
<td>3.20</td>
<td>6.90</td>
<td></td>
<td>2.91</td>
<td>10.0</td>
<td>3.13</td>
<td>2.4</td>
</tr>
<tr>
<td>Cºtw</td>
<td>3.09</td>
<td>5.41</td>
<td>-3.4</td>
<td>2.71</td>
<td>14.0</td>
<td>2.84</td>
<td>9.2</td>
</tr>
<tr>
<td>Hºrst</td>
<td>2.54</td>
<td>7.45</td>
<td>-20.6</td>
<td>2.60</td>
<td>-2.3</td>
<td>2.69</td>
<td>-5.8</td>
</tr>
</tbody>
</table>

Figure 5. Resistance to traction by diametric compression.

Table 6 and Figure 6 shows the fr values obtained in the test and K values by applying formulas (3) (A.C.P.A., 2000) and (4) (Raphael, 1984).

\[
K = \frac{f_{r}}{(f_{cm})^{1/2}} \quad \text{(3)}
\]

\[
K = \frac{f_{r}}{(f_{cm})^{2/3}} \quad \text{(4)}
\]

K calculated values result to be inferior in more than a 9% than the recommended minimum of A.C.P.A as regards round aggregates (K=0.62); and more than 25% inferior than the minimum recommended by Raphael (K=0.445) for Cºtw. Nevertheless, it covers the minimum for Cºtw recommended by A.C.P.A.

Table 6. Bending resistance of the different concretes.

<table>
<thead>
<tr>
<th>Type of Cº</th>
<th>fr (MPa)</th>
<th>Variation Coefficient CV (%)</th>
<th>% f’c variation as regards Hc</th>
<th>K (A.C.P.A.)</th>
<th>Dif (%)</th>
<th>K (Raphael)</th>
<th>Dif (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cºc</td>
<td>3.65</td>
<td>8.70</td>
<td></td>
<td>0.64</td>
<td>3.23</td>
<td>0.36</td>
<td>-19.10</td>
</tr>
<tr>
<td>Cºuw</td>
<td>3.27</td>
<td>9.51</td>
<td>-10.36</td>
<td>0.62</td>
<td>0.00</td>
<td>0.36</td>
<td>-19.10</td>
</tr>
<tr>
<td>Cºtw</td>
<td>2.85</td>
<td>12.43</td>
<td>-21.88</td>
<td>0.56</td>
<td>-9.68</td>
<td>0.33</td>
<td>-25.84</td>
</tr>
</tbody>
</table>

Figure 6. Bending resistance of the different concretes.
According to the ACI 214 regulation, the variation coefficient values (CV) determined respond from very good to excellent concrete quality.

However, the fracture mechanics of the tested samples were developed partially through the mortar, for all cases; there was a low adhesion between it and the coarse aggregate. Figure 7.

4 CONCLUSIONS

Concretes with recycled material do not reach in any of the cases the mechanic resistances determined by the sample concrete, either by simple compression, indirect tensile strength or bending.

The batches made with untreated waste C\(^{\text{uw}}\) show less resistance than those made with treated waste C\(^{\text{tw}}\).

There is an acceptable response to bending of the C\(^{\text{tw}}\). It reaches a characteristic resistance of 21 MPa, which makes it suitable for the construction of different parts of a road infrastructure, i.e. curbs, dips, drains, drainage chambers, New Jersey barriers, etc.

It was concluded that concretes made with untreated recycled materials are not suitable for structural usage. Nevertheless, if its treatment in plant is systematized, its usage in road infrastructure could be a very convenient alternative from an environmental and economic point of view.

5 REFERENCES


CBR BEHAVIOR OF ZINC FACTORY SLAG FOR HIGHWAY EMBANKMENT

C.1 Management of Road Infrastructure Assets

<table>
<thead>
<tr>
<th>AUTHOR (Capitalize Family Name)</th>
<th>POSITION</th>
<th>ORGANIZATION</th>
<th>COUNTRY</th>
</tr>
</thead>
<tbody>
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<td>Bekir AKTAŞ</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CO-AUTHOR(S) (Capitalize Family Name)</th>
<th>POSITION</th>
<th>ORGANIZATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Ebubekir BAYDILLI</td>
<td>- Civil Engineer</td>
<td>- Kayseri 6th Regional Directorate of General Directorate of Highways</td>
</tr>
<tr>
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<td>- Research Assistant</td>
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</tr>
</tbody>
</table>

E-MAIL (for correspondence) baktas@erciyes.edu.tr

KEYWORDS: CBR, Zinc Factory Slag, Road Embankment

ABSTRACT:
The recycling of industrial waste materials in civil engineering area has a great importance for many years. Especially highway embankment has a remarkable potential among the other construction sectors because of the needs of so much material. In this study, California Bearing Ratio (CBR) behavior of the four different groups of Zinc Factory Slags (ZFS) was investigated. A series of modified proctor tests were carried out to determine optimum water content and maximum dry density before CBR tests. First results of CBR tests demonstrated that there is a possibility to use of these slags in embankment/road construction according to technical specifications of general directorate of Turkish highways.
INTRODUCTION

A remarkable waste material has been emerged in all over the world for years. Investigation of usability or recycling of waste materials is an important topic for engineers and researchers. Especially in developed or developing countries have started to reuse or recycling these materials in some sectors because of causing disposal and environmental problem (Aubert et al. 2006; Ministry of Environment 2008). Highway engineering is an important field to evaluate of waste materials. Environmental suitability is a major concern in the consideration of using waste slag as highway construction materials in some layers or road embankments (Huang et al. 2007). Also chemical composition of waste materials must be assessed for heavy metals content when used in road construction. The performance of waste slags in road embankment depends on the physical properties and it’s stiffness. Among the various methods of evaluating the waste slag strength, CBR test is important for highway engineer so this study is focus on compression of soaked and unsoaked CBR value. California Bearing Ratio (CBR) is a measure of strength of soil materials to penetration of standard plunger under controlled density and moisture conditions. CBR is a method of evaluating the materials or subgrade for the flexible pavement design. In this study a series of modified proctor tests were carried out to determine optimum water content before CBR tests. First results of CBR tests demonstrated that there is a possibility to use of these slags in embankment/road construction according to technical specifications of general directorate of Turkish highways.

As with other waste materials, the waste slags produced by the zinc industry have great potential for use in road construction. Havanagi et al. (2008) investigated the usability of copper slag, zinc slag, steel slag and pond ash that were collected from different industries in road embankments and subgrade layers. They also studied these waste materials as a replacement for fine aggregate in bituminous layers. The authors reported that these waste materials have potential for use in road embankments. Also, they reported that copper and zinc slag may partially be used as a replacement for fine aggregate in bituminous mixtures. Barna et al. (2004) studied the leaching behaviour of waste materials containing primary lead and zinc slags. They used these waste materials as a partial substitute for sand in two road materials, namely sand-cement and sand-bitumen. The authors concluded that the release of Pb and Zn from the materials in a saturated scenario was controlled by the pH of the leachates (Hughes and Halliburton, 1973). The aim of this study investigation of California Bearing Ratio (CBR) behavior of the four different groups of Zinc Factory Slags (ZFS) for road embankment.

MATERIALS AND METHODS

The main purpose of this study was to evaluate the usability of ZFC for highway embankment. Initially, physical properties of ZFS are determined and then optimum moisture contents of the slags are determined using with modified proctor test. Finally, CBR tests are performed for each ZFS.

Zinc Factory Slag
The waste slags were taken from ÇİNKOM company which is located in the city of Kayseri, TURKEY. Waste slag is the inorganic material resulting from the processing of raw materials in the production of zinc and lead in a Waelz kiln unit. The properties of waste slag depend on the components of the raw materials, the crushing-screening unit and the process in the Waelz kiln unit. About 2 million m³ of waste slag are produced in the factory located in the city of Kayseri (Turkey) alone. The plant has a 350,000 – 400,000
tonnes per year raw material processing capacity. This means that the amounts of waste slag will continuously increase in time. Chemical compositions of zinc slag mostly are consisting of CaO, SiO$_2$, Al$_2$O$_3$, Fe and other elements. There are four group of slag in the Zinc Factory and these slags have stocked various times from established of the factory. The gradation of waste slags can be seen in Figure 1. The chemical composition and gradations are also various properties because of production process and used raw materials. The ranges of chemical composition of ZFS are in Table 1.

![Figure 1. Gradation curves of four group of ZFS](image)

**Table 1. Chemical Composition of ZFSs**

<table>
<thead>
<tr>
<th>Compounds</th>
<th>ZFS-1 (%)</th>
<th>ZFS-2 (%)</th>
<th>ZFS-3 (%)</th>
<th>ZFS-4 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe$_2$O$_3$</td>
<td>17.96</td>
<td>28.73</td>
<td>29.79</td>
<td>34.86</td>
</tr>
<tr>
<td>CaO</td>
<td>24.23</td>
<td>22.75</td>
<td>20.67</td>
<td>23.76</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>12.70</td>
<td>10.30</td>
<td>10.02</td>
<td>8.96</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>4.38</td>
<td>6.44</td>
<td>7.22</td>
<td>7.64</td>
</tr>
<tr>
<td>MgO</td>
<td>2.19</td>
<td>2.16</td>
<td>2.14</td>
<td>2.62</td>
</tr>
<tr>
<td>SO$_3$</td>
<td>1.25</td>
<td>1.89</td>
<td>0.78</td>
<td>1.60</td>
</tr>
<tr>
<td>Mn$_2$O</td>
<td>0.43</td>
<td>1.48</td>
<td>1.37</td>
<td>1.76</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>0.30</td>
<td>0.90</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.32</td>
<td>0.65</td>
<td>0.88</td>
<td>0.93</td>
</tr>
<tr>
<td>Cl</td>
<td>0.78</td>
<td>0.36</td>
<td>0.32</td>
<td>0.76</td>
</tr>
</tbody>
</table>

**California Bearing Ratio**

The CBR test was originally developed by O.J. Porter for the California Highway Department during the 1920s. It is a load-deformation test performed in the laboratory or the field, whose results are used to evaluate material stiffness and also determine the thickness of flexible pavement layers. Although actual AASHTO flexible pavements design method uses Resilient Modulus ($M_R$) value as a main parameter, there are a lot of empiric equations to convert CBR values to $M_R$. The CBR test is a small scale penetration test in which a cylindrical plunger of 19.35 cm$^2$ in area cross section is penetrated into a soil mass at the rate of 1.25 mm/minute. Results are taken between the test load versus the penetration of plunger. The penetration resistance of the plunger into a standard sample of crushed stone for the corresponding penetration is called...
standard load (ASTM D188, 2014). The CBR is defined as the ratio of the test load to the standard load, expressed as percentage for a given penetration of the plunger as below:

\[
\text{CBR} = \left( \frac{\text{Test stress}}{\text{Standard stress}} \right) \times 100
\]

**EXPERIMENTAL WORK**

**Proctor’s Compaction Test**

The optimum moisture content and the maximum dry density of the four ZFS samples were determined by performing the Modified Proctor’s test in accordance with Turkish standard procedure (TS EN 1900-1, ASTM D698-2012). The dry density was determined and plotted against the corresponding water content to find the optimum moisture content and the corresponding maximum dry density. The compaction curves of four group of ZFS were found to be flat indicating insensitiveness of dry density with the variation in moisture content. The Maximum Dry Density (MDD) of these slags varied in the range of 15.92 kN/m³ to 20.71 kN/m³ and Optimum moisture content varied in the range of 8 - 19%. These values are within Turkish Highway specification limits for road embankment. The values of optimum moisture content and maximum dry density of ZFS samples are shown in Table 1.

<table>
<thead>
<tr>
<th>Zinc Factory Slag Types</th>
<th>Optimum Moisture content</th>
<th>Max Dry Density (kN/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZFS1</td>
<td>19.00</td>
<td>16.02</td>
</tr>
<tr>
<td>ZFS2</td>
<td>17.50</td>
<td>15.92</td>
</tr>
<tr>
<td>ZFS3</td>
<td>8.00</td>
<td>20.71</td>
</tr>
<tr>
<td>ZFS4</td>
<td>17.00</td>
<td>17.22</td>
</tr>
</tbody>
</table>

**California Bearing Ratio Test**

CBR test is one of the most commonly used method to evaluate the strength of unbound materials. The CBR samples are prepared according to optimum moisture content and max dry density for each ZFS. From the load penetration curve, the CBR value corresponding to the 2.5 mm and 5mm penetration was determined. The CBR charts corresponding to these penetrations for each ZFS is given in Figure 2.
It was observed that soaked CBR values of ZFSs varied in the range 46 - 57 % and 81 - 94 % at 2.5 mm and 5.0 mm penetration respectively. The results if CBR values of all ZFS are seen Table 2.

Table 2. CBR results at 2.5 and 5.0 mm penetration of soaked ZFS samples

<table>
<thead>
<tr>
<th>Zinc Factory Slag Types</th>
<th>CBR for 2.5 mm penetration (%)</th>
<th>CBR for 5.0 mm penetration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZFS1</td>
<td>57.7</td>
<td>94.0</td>
</tr>
<tr>
<td>ZFS2</td>
<td>46.6</td>
<td>81.5</td>
</tr>
<tr>
<td>ZFS3</td>
<td>54.0</td>
<td>81.5</td>
</tr>
<tr>
<td>ZFS4</td>
<td>51.8</td>
<td>85.8</td>
</tr>
</tbody>
</table>

Figure 2. CBR test graphs of soaked ZFS samples
In addition to soaked CBR tests, all ZFS samples are performed unsoaked CBR test. In figure 3, CBR charts of all unsoaked samples are seen. After CBR corrections are calculated, it was observed that unsoaked CBR values of ZFSs varied in the range 40 - 63 % and 62 - 97 % at 2.5 mm and 5.0 mm penetration respectively.

Table 3. CBR results at 2.5 and 5.0 mm penetration of unsoaked ZFS samples

<table>
<thead>
<tr>
<th>Zinc Factory Slag Types</th>
<th>CBR for 2.5 mm penetration (%)</th>
<th>CBR for 5.0 mm penetration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZFS1</td>
<td>57.1</td>
<td>95.2</td>
</tr>
<tr>
<td>ZFS2</td>
<td>57.1</td>
<td>87.6</td>
</tr>
<tr>
<td>ZFS3</td>
<td>40.0</td>
<td>62.9</td>
</tr>
<tr>
<td>ZFS4</td>
<td>62.9</td>
<td>97.1</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Four group of Zinc factory slags are investigated for their suitability in road embankment construction. Brief summary of conclusions are given below:

- Maximum Dry Density (MDD) of these slags varied in the range of 15.92 kN/m³ to 20.71 kN/m³ and optimum moisture content varied in the range of 8 - 19%.
- CBR values of ZFSs varied in the range 51 - 57 % and 81 - 94 % at 2.5 mm and 5.0 mm penetration respectively.
- CBR values of ZFSs varied in the range 40 - 68 % and 97 - 102 % at 2.5 mm and 5.0 mm penetration respectively.

Overall, this study has showed that there is remarkable potential for the use of zinc factory slags in road embankment construction. It would be very beneficial in terms of waste management and reuse of waste materials. Also, further tests such as resilient modulus, leaching, direct shear and permeability test etc. can be examined in a future study.

ACKNOWLEDGEMENTS

This study was supported by the Scientific Research Projects Coordination Department of Erciyes University (Project Number: FBA-2015-5890). Authors of this study express their gratitude to ERÜ/BAP for sponsoring the project. Also, the authors would like to thank the Çinkom Company for their assistance.
REFERENCES


SULFUR EXTENDED ASPHALT (SEA) – PROPERTIES WITH THE CHANGE OF TIME

6.2 Modified Materials and Pavement Systems

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Sulfur is a chemical element that is used for many industrial productions. Today sulfur production is as a side product of industrial processes such as oil refining. Due to the huge amounts of oil refining productions, nowadays excess of Sulfur and its usage areas became a major Task for the Oil & Gas production Countries.

In the early 1970’s there was the idea of usage of excessive sulfur, obtain during the refining process, in hot mix production. Today also the same demand exists. For this purpose Saudi ARAMCO has developed Engineering Standard (SAES Q-006) that uses Pelletized Elemental Sulfur. As an Asphalt Contractor, in our running ARAMCO projects, we also started to apply SEA and carried out some laboratory/site trials in Saudi Arabia. This trial and its findings attracted our attention to SEA and we have started a research in our Central Laboratory in Ankara/Turkey.

In this research addition of sulfur and its effects to bitumen and hot mix with variable contents of sulfur addition and their time relation were investigated.

Bitumen tests were carried out to the 2, 4, 7, 10 and 15 days cured the laboratory prepared samples starting from 0%, 10%, 20%, 30% and 40% sulfur added bitumen during this research. Again in the same curing times, Marshall Stability/Flow and Indirect Tensile Strength relations were determined to the laboratory prepared asphalt samples with the above sulfur contents.

KEYWORDS:
Sulfur Extended Asphalt,
Sulfur Extended Asphalt (SEA) – Properties with the change of time

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1 INTRODUCTION

Sulfur is a chemical element that is used for many industrial productions. Today sulfur production is as a side product of industrial processes such as oil refining. Due to the huge amounts of oil refining productions, nowadays excess of Sulfur and its usage areas became a major Task for the Oil & Gas production Countries.

In the past, sulfur is used for many applications as well as the binding material for many different areas. In the beginning of 19th century with the discovery of the acid-resistance property of the sulfur, its area of application increased. (W.C. McBee et al. 1980) In the early 1970s, there was an idea to use the excessive sulfur obtained in the course of the refining process in hot mix production. Today, same demand also exists. For this purpose, Saudi ARAMCO has developed Engineering Standard (SAES Q-006) that uses Pelletized Elemental Sulfur. As an Asphalt Contractor, in our ongoing ARAMCO projects, we also started to apply SEA and carried out some laboratory/site trials in Saudi Arabia. This trial and its findings attracted our attention to SEA and we have started a research in our Central Laboratory in Ankara/Turkey.

2 SAUDI ARABIA EXPERIENCE

In our currently ongoing Jazan Refinery and Marine Terminal Project, together with the traditional hot mix asphalt, SEA is also foreseen partially. In order to create the SEA mixture, it was decided to continue with the same asphalt designs and raw sources of the production of the traditional asphalt, crushed basalt aggregates and 50/70 pen Ras Tanura ARAMCO Refinery bitumen. According to SAES Q-006, 30% by weight of bitumen in the mix shall be replaced with pelletized elemental sulfur as a binding agent. Despite of this judgment, in order to understand the properties of SEA, tests were carried out for 15%, 25% and 30% of sulfur added mixes in the site laboratory. Bitumen additionally mixed with sulfur was also tested. As a general trend, with the increasing content of sulfur, bitumen penetration increased with a little decrease of the softening point whereas asphalt stability increased slightly without a considerable change in flow values. However, during these site laboratory trials, we faced unexpected results which are also not following this general trend. Due to the limited time and the facilities, we decided to enlarge this research in our central laboratory located in Turkey and continued with the site trial in Jazan Project.

For the site trial, we selected a Project location with the heaviest traffic (in front of the steel factory). It was a 300 m long section, single carriageway; both AC Base Course (7 cm) and AC Wearing Course (5 cm) were constructed in March 2015. In order to correlate the performance of SEA against the traditional asphalt, 100 meters of this trial area were constructed without adding any sulfur. The remaining 200 meters were constructed with 15%, 25% and 30% of sulfur extended mixes for both lanes and equal portions of the road. In the asphalt plant, mixing temperatures were kept at around 135°C and sulfur was directly added to the mixing system with an air blow additive system. Total mixing time for 2 tons of a batch was 30 seconds; during these 30 seconds, only within the last 10 seconds, sulfur was introduced into the mix. During the compaction of SEA, we observed slight sliding of the mix under the rollers and small cracks appearing on the surface. After the commencement of the construction of the Project road, sulfur mixing time was increased to 30 seconds — same as for the total batch mixing duration — and after this, we observed no sliding of the mix under the rollers. Up till the present day, this trial area has been under traffic without any defects or failure.

3 LABORATORY TESTS

In this research, we investigated the addition of sulfur and the effect it has on the bitumen and hot mix with variable contents of sulfur addition and their time relation. In order to correlate the performance of the mix, we selected the Çaliseki AC Wearing Course design which is used in highway construction and has proved its performance on the road. Aggregates used were crushed limestone with the following grading (please see table 1 and figure 1):
Table 1. Aggregate grading

<table>
<thead>
<tr>
<th>Sieve Sizes, mm</th>
<th>19,1</th>
<th>12,7</th>
<th>9,5</th>
<th>4,76</th>
<th>2,0</th>
<th>0,420</th>
<th>0,177</th>
<th>0,075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passing Percantage, %</td>
<td>100,0</td>
<td>89,6</td>
<td>75,5</td>
<td>49,4</td>
<td>32,6</td>
<td>13,8</td>
<td>9,2</td>
<td>5,9</td>
</tr>
</tbody>
</table>

Figure 1. Limestone aggregate gradation curve

Initially, bitumen mixtures were prepared and tested. Virgin bitumen was Kırıkkale 50/70 penetration. Sulfur is added to the bitumen with 10%, 20%, 30% and 40% by weight. Bitumen is heated up to 140°C and kept in this temperature during mixing. Sulfur is being mixed for 30 minutes in a laboratory type pug mill with the same unchanging speed for all percentages. Penetration, softening point, ductility, and specific gravity tests were carried out on the 2\textsuperscript{nd}, the 4\textsuperscript{th}, the 7\textsuperscript{th}, the 10\textsuperscript{th}, and the 15\textsuperscript{th} day of curing of the samples prepared in the laboratory. During the curing period, the prepared samples were stored at room temperature. After completion of the first set of tests, we observed some unexpected results which did not follow the general trend observed in our Saudi Arabia experience. Thus, two additional samples were prepared with the same method of preparation and were tested with the abovementioned tests and periods. In total, 3 tests for all of the abovementioned periods and the sulfur contents were conducted. All tests were conducted in accordance with the ASTM and AASHTO standard test methods. You can find the average of all of the results in the following table. (please see table 2)

<table>
<thead>
<tr>
<th>Testing</th>
<th>Day of testing</th>
<th>0% Sulfur</th>
<th>10% Sulfur</th>
<th>20% Sulfur</th>
<th>30% Sulfur</th>
<th>40% Sulfur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration at 25°C</td>
<td>2</td>
<td>54,5</td>
<td>74,6</td>
<td>69,0</td>
<td>82,3</td>
<td>79,7</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>80,0</td>
<td>84,2</td>
<td>78,9</td>
<td>73,7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>78,2</td>
<td>79,5</td>
<td>58,8</td>
<td>66,5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>78,3</td>
<td>71,3</td>
<td>70,9</td>
<td>64,8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>72,5</td>
<td>63,6</td>
<td>65,2</td>
<td>66,4</td>
<td></td>
</tr>
<tr>
<td>Softening Point</td>
<td>2</td>
<td>49,2</td>
<td>47,5</td>
<td>49,4</td>
<td>48,2</td>
<td>46,4</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>45,4</td>
<td>46,1</td>
<td>48,5</td>
<td>47,1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>45,4</td>
<td>46,3</td>
<td>49,9</td>
<td>52,9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>46,7</td>
<td>48,9</td>
<td>47,5</td>
<td>47,6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>48,5</td>
<td>48,8</td>
<td>46,9</td>
<td>48,4</td>
<td></td>
</tr>
<tr>
<td>Ductility at 25°C</td>
<td>2</td>
<td>100+</td>
<td>100+</td>
<td>59,7</td>
<td>34,7</td>
<td>61,8</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>100+</td>
<td>65,9</td>
<td>69,7</td>
<td>48,0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>100+</td>
<td>84,7</td>
<td>61,5</td>
<td>65,8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>100+</td>
<td>91,1</td>
<td>72,1</td>
<td>92,7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>100+</td>
<td>92,4</td>
<td>80,1</td>
<td>67,3</td>
<td></td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>2</td>
<td>1,030</td>
<td>1,078</td>
<td>1,130</td>
<td>1,137</td>
<td>1,137</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1,079</td>
<td>1,119</td>
<td>1,126</td>
<td>1,127</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>1,086</td>
<td>1,116</td>
<td>1,135</td>
<td>1,122</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1,079</td>
<td>1,125</td>
<td>1,126</td>
<td>1,122</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1,095</td>
<td>1,106</td>
<td>1,118</td>
<td>1,131</td>
<td></td>
</tr>
</tbody>
</table>
After the addition of Sulfur, bitumen penetration values increased for all of the sulfur contents. It is worth noting that the samples to which 30% and 40% of sulfur was added gave the highest values in the first 2 days — in the subsequent days, however, their values start to drop below the values of the samples to which 10% and 20% of sulfur was added. After 15 days, samples to which 10% of sulfur was added, showed the highest penetration values. (please see figure 2)

![Figure 2. Change in sulfur extended bitumen penetration values over time](image)

Except several instances, softening point values were less than the virgin bitumen value. It is also interesting that the 10% sulfur added samples showed the greatest change in values within a short period — after 15 days, however, values of nearly all of the samples came close to each other. (please see figure 3)

![Figure 3. Sulfur extended bitumen softening point values change by the time](image)

In the course of the ductility test, virgin bitumen and bitumen with 10% of sulfur added to it could not rupture in 100cm. In 2, 4 days period, the 30% and 40% sulfur added samples showed very low ductility values, down to 40’s. However, as time passes, the ductility values are increasing up to 80’s. Strangely, 30% sulfur added samples affected the ductility results more than 40% sulfur added samples. (please see figure 4)

![Figure 4. Sulfur extended bitumen ductility values change by the time](image)

Purely introduced sulfur specific gravity is around 2.0. As expected, all the sulfur added samples showed higher specific gravity values than the virgin bitumen. Virgin bitumen specific gravity is 1.030. After the addition of
10% sulfur, specific gravity increased up to 1.078 and for 40% sulfur added samples up to 1.137. Except 10% sulfur added samples, all of the other sulfur added samples showed slightly decreasing values over time. (please see figure 5)

Figure 5. Sulfur extended bitumen specific gravity change by the time

Optimum bitumen for the original asphalt design is 5.04% by weight of mix from Çalıseki. The replacement of asphalt with sulfur is based on the volume. In order to calculate the content of the sulfur extended binder, we selected the following equation based on Berau of Mines work. (W.C. McBee et al. 1980)

\[
Total\ Binder\ Mass\ (%) = A \left( \frac{100\ R}{100\ R- Ps (R-G_{\text{asp}})} \right) \tag{1}
\]

Where:
- \( A \) = Mass of bitumen content in the original mix design
- \( R \) = Sulfur/asphalt specific gravity ratio
- \( Ps \) = Mass % sulfur in total binder
- \( G_{\text{asp}} \) = Specific Gravity

Example Calculation:
- \( A = \) Optimum bitumen content is 4.58 %
- \( R = G_{\text{sulfur}} \) is 2.0 \( G_{\text{asp}} \) is 1.03 so 2.0/1.03 is 1.942
- \( Ps = \) Assume 20% sulfur added sample
- \( G_{\text{asp}} = \) Specific Gravity of bitumen is 1.03

\[
Total\ Binder\ Mass\ (%) = 4.58 \left( \frac{100 \times 1.942}{100 \times 1.942-20 (1.942-1.03)} \right) = 5.03\% \tag{2}
\]

From this equation the following total binder mass percentages were found. (please see table 3)

<table>
<thead>
<tr>
<th>Table 3. SEA binder contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur ratio</td>
</tr>
<tr>
<td>Bitumen content by weight of aggregate, %</td>
</tr>
<tr>
<td>Bitumen content by weight of total mix, %</td>
</tr>
<tr>
<td>Content of sulfur by weight of total mix, %</td>
</tr>
<tr>
<td>Content of bitumen by weight of total mix, %</td>
</tr>
</tbody>
</table>

With the calculated binder contents, aggregates and sulfur added bitumen is mixed in a laboratory mixer. During the mixing, the temperature of the mix was kept from 135°C to 140°C. After having been properly mixed, samples were kept for two hours in an oven at \( T=140°C \) and then 75 blows standard Marshall compacted samples were prepared. For each sulfur percentages, 30 pieces of compacted specimens were prepared and bulk specific gravities were determined. Some specimens showed more than ±0.020 difference in bulk densities; thus, such samples were discharged and new ones were prepared. Also, for each sulfur percentages, we carried out the Maximum Theoretical Specific Gravity Test (rice test). At first, according to the air void results, samples were divided into five groups, each to be tested at a different time: on the 2nd, the 4th, the 7th, the 10th, and the 15th day. Each group contained 6 compacted specimens. Also, in order to determine the Loss of Stability results, these groups were also divided into two sub-groups. For the first sub-group, ordinary Marshall Stability test was carried out; the second sub-group was kept in water at...
Stability tests were carried out. (please see table 5) and voids filled with asphalt were also very close to each other. For these samples, Marshall Stability/Flow and Loss of sulfur and bitumen. Except for the 40% sulfur added samples, results for the air voids, voids in mineral aggregate, 0°C for 24 hours and tested for stability. All tests were conducted according to MS-2 Asphalt Institute Mix Designs Methods. (please see table 4)

<table>
<thead>
<tr>
<th>Sulfur Content, %</th>
<th>Age of Specimens</th>
<th>Sample Curing</th>
<th>Bitumen Content by weight of total mix, %</th>
<th>Bulk Specific Gravity of Specimens (Gmb)</th>
<th>Max. Theoretical Specific Gravity (Gmm)</th>
<th>Air Voids, %</th>
<th>VMAa, %</th>
<th>Vfa, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>1 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td>4,58</td>
<td>2,444</td>
<td>2,443</td>
<td>3,0</td>
<td>3,0</td>
<td>13,47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cond. Samp., 24 h. 60°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>2 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td></td>
<td>2,433</td>
<td>3,35</td>
<td>14,04</td>
<td>76,2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cond. Samp., 24 h. 60°C</td>
<td></td>
<td>2,441</td>
<td>3,02</td>
<td>13,75</td>
<td>78,0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td></td>
<td>2,434</td>
<td>3,30</td>
<td>14,00</td>
<td>76,4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cond. Samp., 24 h. 60°C</td>
<td></td>
<td>2,433</td>
<td>3,34</td>
<td>14,03</td>
<td>76,2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td></td>
<td>2,435</td>
<td>3,29</td>
<td>13,99</td>
<td>76,5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cond. Samp., 24 h. 60°C</td>
<td></td>
<td>2,433</td>
<td>3,33</td>
<td>14,03</td>
<td>76,2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td></td>
<td>2,433</td>
<td>3,34</td>
<td>14,04</td>
<td>76,2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cond. Samp., 24 h. 60°C</td>
<td></td>
<td>2,432</td>
<td>3,41</td>
<td>14,10</td>
<td>75,8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td></td>
<td>2,428</td>
<td>3,53</td>
<td>14,21</td>
<td>75,1</td>
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<tr>
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<td></td>
<td>Cond. Samp., 24 h. 60°C</td>
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<td>75,1</td>
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</tr>
<tr>
<td>20%</td>
<td>2 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td></td>
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<td>3,40</td>
<td>14,25</td>
<td>76,2</td>
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<td>2,432</td>
<td>3,45</td>
<td>14,30</td>
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<td>3,44</td>
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<td>75,9</td>
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<td>7 days</td>
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<td>14,29</td>
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<td>14,29</td>
<td>76,0</td>
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<td>10 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
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<td>2,433</td>
<td>3,41</td>
<td>14,26</td>
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<td>14,27</td>
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<tr>
<td>30%</td>
<td>2 days</td>
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<td>Cond. Samp., 24 h. 60°C</td>
<td></td>
<td>2,438</td>
<td>3,08</td>
<td>14,31</td>
<td>78,5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td></td>
<td>2,439</td>
<td>3,06</td>
<td>14,29</td>
<td>78,6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cond. Samp., 24 h. 60°C</td>
<td></td>
<td>2,438</td>
<td>3,10</td>
<td>14,33</td>
<td>78,3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td></td>
<td>2,439</td>
<td>3,07</td>
<td>14,30</td>
<td>78,5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cond. Samp., 24 h. 60°C</td>
<td></td>
<td>2,439</td>
<td>3,05</td>
<td>14,28</td>
<td>78,7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td></td>
<td>2,438</td>
<td>3,10</td>
<td>14,32</td>
<td>78,4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cond. Samp., 24 h. 60°C</td>
<td></td>
<td>2,438</td>
<td>3,10</td>
<td>14,33</td>
<td>78,4</td>
<td></td>
</tr>
<tr>
<td>40%</td>
<td>2 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td></td>
<td>2,428</td>
<td>3,89</td>
<td>14,96</td>
<td>74,0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cond. Samp., 24 h. 60°C</td>
<td></td>
<td>2,428</td>
<td>3,91</td>
<td>14,98</td>
<td>73,9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td></td>
<td>2,428</td>
<td>3,88</td>
<td>14,95</td>
<td>74,1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cond. Samp., 24 h. 60°C</td>
<td></td>
<td>2,428</td>
<td>3,88</td>
<td>14,95</td>
<td>74,1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td></td>
<td>2,428</td>
<td>3,90</td>
<td>14,97</td>
<td>73,9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cond. Samp., 24 h. 60°C</td>
<td></td>
<td>2,428</td>
<td>3,87</td>
<td>14,94</td>
<td>74,1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td></td>
<td>2,428</td>
<td>3,87</td>
<td>14,95</td>
<td>74,1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cond. Samp., 24 h. 60°C</td>
<td></td>
<td>2,428</td>
<td>3,88</td>
<td>14,95</td>
<td>74,1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 days</td>
<td>Uncon. Samp., 30 min. 60°C</td>
<td></td>
<td>2,429</td>
<td>3,83</td>
<td>14,91</td>
<td>74,3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cond. Samp., 24 h. 60°C</td>
<td></td>
<td>2,429</td>
<td>3,85</td>
<td>14,93</td>
<td>74,2</td>
<td></td>
</tr>
</tbody>
</table>

As can be seen from the results, bulk specific gravity values stay constant regardless of the different contents of sulfur and bitumen. Except for the 40% sulfur added samples, results for the air voids, voids in mineral aggregate, and voids filled with asphalt were also very close to each other. For these samples, Marshall Stability/Flow and Loss of Stability tests were carried out. (please see table 5)

Table 5. Summarized laboratory results for Marshall Stability/Flow and Loss of Stability Tests
<table>
<thead>
<tr>
<th>Testing</th>
<th>Days</th>
<th>0% Sulfur</th>
<th>10% Sulfur</th>
<th>20% Sulfur</th>
<th>30% Sulfur</th>
<th>40% Sulfur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marshall Stability, kg</td>
<td>2</td>
<td>1379</td>
<td>1318</td>
<td>1357</td>
<td>1275</td>
<td>1460</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1416</td>
<td>1342</td>
<td>1325</td>
<td>1450</td>
<td>1466</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>1384</td>
<td>1413</td>
<td>1450</td>
<td>1450</td>
<td>1466</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1244</td>
<td>1428</td>
<td>1518</td>
<td>1416</td>
<td>1416</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1292</td>
<td>1423</td>
<td>1474</td>
<td>1485</td>
<td>1485</td>
</tr>
<tr>
<td>Marshall Stability Cond., kg</td>
<td>2</td>
<td>1477</td>
<td>1284</td>
<td>1290</td>
<td>1460</td>
<td>1422</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1218</td>
<td>1353</td>
<td>1261</td>
<td>1349</td>
<td>1349</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>1292</td>
<td>1263</td>
<td>1332</td>
<td>1179</td>
<td>1179</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1163</td>
<td>1356</td>
<td>1406</td>
<td>1422</td>
<td>1422</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1174</td>
<td>1273</td>
<td>1306</td>
<td>1306</td>
<td>1306</td>
</tr>
<tr>
<td>Loss of Stab., %</td>
<td>2</td>
<td>-7.1%</td>
<td>2.6%</td>
<td>5.0%</td>
<td>-14.5%</td>
<td>2.6%</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>14.0%</td>
<td>-0.8%</td>
<td>4.8%</td>
<td>4.9%</td>
<td>4.9%</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>6.7%</td>
<td>10.6%</td>
<td>8.1%</td>
<td>19.5%</td>
<td>19.5%</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>6.5%</td>
<td>5.1%</td>
<td>7.3%</td>
<td>-0.4%</td>
<td>-0.4%</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>9.1%</td>
<td>10.6%</td>
<td>11.4%</td>
<td>12.4%</td>
<td>12.4%</td>
</tr>
<tr>
<td>Marshall Flow, mm</td>
<td>2</td>
<td>3.4</td>
<td>3.0</td>
<td>3.5</td>
<td>3.1</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4.0</td>
<td>3.0</td>
<td>3.4</td>
<td>3.7</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3.6</td>
<td>3.5</td>
<td>3.3</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>2.9</td>
<td>3.3</td>
<td>3.6</td>
<td>4.1</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>3.0</td>
<td>3.3</td>
<td>3.5</td>
<td>4.3</td>
<td>4.3</td>
</tr>
</tbody>
</table>

With the addition of 10% sulfur, Marshall Stability decreases over time. However, for the other contents, Marshall Stability gradually increases. (please see figure 6)

![Figure 6. SEA Marshall Stability change over time](image)

Except 40% sulfur added samples, Marshall flow values are not affected by the addition of sulfur and do not depend on time. 40% sulfur added samples show slight increase over time. (please see figure 7)
Except for the 30% sulfur added samples tested on the 2nd day, all of the result of the Loss of Stability tests show higher loss values. However, they are still in the acceptable margin which is less than 20% of Loss. Also, there is a trend that, over time, stability losses are increasing. (please see figure 8)

Additionally, for each sulfur percentage, 25 blows compacted specimens (30 pieces for each sulphur content) were prepared in order to conduct the ASTM D-6931 Indirect tensile strength test and were divided into groups in the same way. Summarized results of the specimens can be found below. (please see table 6)

<table>
<thead>
<tr>
<th>Testing</th>
<th>Days</th>
<th>0% Sulfur</th>
<th>10% Sulfur</th>
<th>20% Sulfur</th>
<th>30% Sulfur</th>
<th>40% Sulfur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect Tensile Strength, kg/cm²</td>
<td>4</td>
<td>11.96</td>
<td>6.92</td>
<td>6.32</td>
<td>8.85</td>
<td>8.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.66</td>
<td>1.90</td>
<td>1.39</td>
<td>3.51</td>
<td>1.68</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>6.57</td>
<td>7.37</td>
<td>9.84</td>
<td>10.90</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.71</td>
<td>1.70</td>
<td>2.50</td>
<td>2.29</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>7.17</td>
<td>7.64</td>
<td>10.27</td>
<td>8.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.90</td>
<td>1.73</td>
<td>3.82</td>
<td>2.42</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>7.86</td>
<td>8.97</td>
<td>10.63</td>
<td>8.64</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.35</td>
<td>2.09</td>
<td>4.33</td>
<td>2.27</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Testing</th>
<th>Days</th>
<th>0% Sulfur</th>
<th>10% Sulfur</th>
<th>20% Sulfur</th>
<th>30% Sulfur</th>
<th>40% Sulfur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect Tensile Strength Ratio, %</td>
<td>4</td>
<td>80.8%</td>
<td>27.5%</td>
<td>22.1%</td>
<td>39.7%</td>
<td>20.6%</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>26.0%</td>
<td>23.1%</td>
<td>25.4%</td>
<td>21.0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>26.5%</td>
<td>22.6%</td>
<td>37.2%</td>
<td>28.7%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>29.9%</td>
<td>23.3%</td>
<td>40.7%</td>
<td>26.3%</td>
<td></td>
</tr>
</tbody>
</table>
Indirect tensile strength values of all of the SEA mixtures are considerably lower than the values for the original mix and do not show any change over time. (please see figure 9)

![Figure 9. SEA Indirect Tensile Strength change over time](image)

After having obtained very low Tensile Strength values, in order to understand the water sensitivity of the mix, an additional AASHTO T-182 Coating and Stripping of Bitumen-Aggregate Mixture test was carried out. Average of three consecutive tests were summarized in the table below. (please see table 7)

<table>
<thead>
<tr>
<th>Sulfur ratio</th>
<th>0%</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of coated areas, %</td>
<td>65%</td>
<td>50%</td>
<td>45%</td>
<td>25%</td>
<td>20%</td>
</tr>
</tbody>
</table>

4 CONCLUSIONS

Despite the very low Indirect Tensile Strength results and poor adhesion results, SEA mixtures can be applied successfully in hot dry climate conditions. The main thing is that the addition of sulfur leads to an increase of the Marshall Stability over time. When sulfur and bitumen are mixed, three types of reaction occur:

- The sulfur can react chemically and result in dehydrogenation
- The sulfur will be dissolved in bitumen
- Sulfur in the crystalline form can remain in suspension

Due to these possible sulfur-bitumen reactions, laboratory test results show broad variations. Also, sometimes, the addition of sulfur does not have any direct effect.

Actually, there are three important questions that need to be asked:

1. Are conventional test methods adequate for SEA mixtures?
2. How much of sulfur can dissolve in the bitumen?
3. In which way should sulfur be added to the mixture?

5 ACKNOWLEDGEMENTS

Authors would like to thank Jazan Refinery and Marine Terminal Project staff for their contributions and central laboratory staff employees for their hard work.

REFERENCES


SAES Q-006 Engineering Standard Asphalt and Sulfur Extended Asphalt Concrete Pavement, 2011

Asphalt Institute Manual Series No.2 (MS-2) Mix Design Methods Sixth Edition


Coating and Stripping of Bitumen-Aggregate Mixture, AASHTO T-182 standard test method, 1990
The concrete (rigid) pavements are generally used for high volume and heavy repetitive traffic loads in highway applications and are preferred especially in developed countries such as United States of America, Canada, Germany, Austria and Belgium. Although the number of countries that use concrete pavement technology is relatively less when compared to those using both rigid and flexible pavements, significant differences are found in their specifications and application methods. In this study, several countries that use concrete pavements were selected and their specifications were compared. Those countries were selected such that they have different climatic conditions and involved not only countries from Northern America (USA and Canada), but also from Europe (Germany, Austria, Belgium, Netherlands and United Kingdom). During the comparison, five main titles are chosen, which are i) pavement design (design methodology, rigid pavement type, the design thickness, transverse joint spacing and design life), ii) concrete mix design (allowed cement types, minimum cement content, maximum water/cementitious ratio, minimum 28 days compressive strength, design air content and target slump range), iii) base and subbase design, iv) dowel bars (application methods, dowel diameter spacing and length and alignment tolerance), and v) surface texturing. As a result of this investigation it was found out that among the states considered in US, Washington state utilizes a 50 year service life, which is separated from other three states with that design criteria. Furthermore, the most important differences between North America and Europe were the selection of long term design life and thicker pavement design in European countries. It was also realized that in Europe exposed aggregate surface texturing technique is utilized, which has not been preferred yet in US and Canada. Moreover, European countries require approximately 10-15 MPa higher 28 days concrete compressive strength than US.
GİRİŞ

Herhangi bir mühendislik yapısında olduğu gibi karayolu üstyapı tasarımı ve inşaatında kullanılabileceğimiz malzemenin seçiminde ve kullanılabileceğimiz malzeme arasında seçim yapmak gerektirir gibi bir dizi tekniğin, teknik, ekonomik ve çevresel faktörler dikkate alınır. Teknik faktörler seçilen malzemenin servis ve çevre koşullarındaki fiziksel, kimyasal ve mekanik özellikleri, yapım kolyalığı ve süresi, dayanıklılığı ile kullanıcı güveni ve konforu gibi hususları içerir. Ekonomik faktörler arasında ilk maliyet ve yaşam döngüsü maliyeti yer alır. Ayrıca, son yıllarda ön plana çıkan sürdürülebilirlik bağlamında çevresel faktörler, sosyo-ekonomik faktörler ve ülke ekonomisine etkilerin de düşünülmesi gereklidir.

Karayolu uygulamalarında rijiş (beton) üstyapılar Amerika Birleşik Devletleri, Almanya, Avusturya, Belçika, Kanada gibi gelişmiş ülkelerde daha çok ağır tonajlı tekrarlı yüklerin yoğun olduğu yüksek trafik hacimli yörelerde tercih edilmektedir. Göreceli olarak beton yol teknolojisinden yararlanan ülke sayısı az olmasına rağmen beton yol şartnamelerinde ve uygulama metotlarında önemli farklılıklar görülebilmektedir. Bu çalışmada, farklı iklim koşullarına sahip ABD’deki dört eyalet ile birlikte (Florida, Wisconsin, Washington, Nevada), Kanada, Almanya, Avusturya, Belçika, Hollanda ve İngiltere ülkeleri seçilerek bu ülkelerdeki beton yol şartnameleri incelenmiş ve bu şartnamelerde ön çıkan beş ana başlık altında; i) üstyapı tasarımı (tasarım metodolojisi, beton üstyapı türü, tasarım kalınlığı, enine derz aralıkları ve servis ömrü), ii) temel ve alt temel tasarım, iii) donatı seçimi, iv) yüzey dokulandırması, v) beton malzeme tasarımını (izin verilen çimento türü, min. çimento oranı, max su/çimento oranı, 28 günlük basınç dayanımı), karşılaştırılmıştır.

ÜSTYAPI TASARIMI


Ülkelerde kullanılan derzli donatısız tipik üstyapı tasarımının bir göz atılamak olursa (Tablo 2), ABD’de minimum beton kalınlığının 17 ile 25 cm arasında değiştiği görülecektir. Avusturya’da 5 cm kalınlığında bitümlü bir arada katman temel tabakası ile üst kaplama arasında kullanılmaktadır. Almanya’da ise cesurluklar için 30 ile 50 cm kalınlığında bir don tabakası üzerinde temel ile birlikte beton plaka uygulanmaktadır. Sürekli donatılı beton yollar ise Kanada ve Belçika’da doğrudan uygulanmaktadır, Hollanda’da ise üzerine 5 cm’lik gözenekli asfalt yollar ile birlikte kullanılmaktadır. (Tablo 3)

Komşu plakalar arasındaki yük transferini sağlamak amacıyla önemli bir görev üstlenen kaynağı donatılar ile ilgilidir. Şartnameler incelendiğinde genel olarak kayma donatısının yerleştilmesinde ya temelde önceden sabitlenmiş sehpa düzeninin kullanılarak betonun üzerine döküldüğü ya da manuel veya otomatik yerleşiriciler ile sonradan beton için, yerleşirildiği görülmektedir. Avrupa ülkelerinde özellikle epoksi ve bitümlü kaplamalı donatıların daha çok tercih edildiği Tablo 4’den anlaşılmaktadır. Ayrıca, ilgili tabloda anlaşılan bu örneklerde Avrupa ülkelerinde ABD
eyaletlere oranla daha uzun kayma donatılarının tercih edildiği görülmüş bu fark bazı ülkeler arasında 20 cm’yi aşmıştır. Ancak kayma donatı çapı incelendiğinde özellikle üstüOPYi kaldığını avrupa ülkelerine göre daha büyük çapların seçildiği görülmüştür. Kayma donatısı yerleştirme aralığı ise tüm ülkelerde büyük benzerlik göstermektedir.

Tablo 1. Şartnamelerde yer alan beton yol tasarımına ilişkin veriler

<table>
<thead>
<tr>
<th>Ülke</th>
<th>Tasarım Metodu</th>
<th>Rijit Üstyapı Tipi</th>
<th>Derz Aralığı</th>
<th>Minimum Kalınlık</th>
<th>Tasarım Ömrü</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABD EYALETLERİ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Florida</td>
<td>1993 AASHTO Tasarım Rehberi (DARwin programı)</td>
<td>Derzli Donatısız Beton Yol</td>
<td>4,5 m veya derz kalınlığının 24 katı (Hangisi daha küçükse)</td>
<td>20 cm</td>
<td>20 yıl</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>1972 AASHTO Tasarım Rehberi (WisPAVE programı)</td>
<td>Derzli Donatısız Beton Yol</td>
<td>15 cm kalınlık için 3,5 m, 18 cm kalınlık için 4 m, 20 cm kalınlık için 4,5 m</td>
<td>Kayma donatısız kesit için 15 cm Kayma donatılı kesit için 17 cm</td>
<td>20 yıl</td>
</tr>
<tr>
<td>Washington</td>
<td>1993 AASHTO Tasarım Rehberi</td>
<td>Derzli Donatısız Beton Yol</td>
<td>4,5 m</td>
<td>20 cm</td>
<td>50 yıl</td>
</tr>
<tr>
<td>Nevada</td>
<td>1993 AASHTO Tasarım Rehberi</td>
<td>Derzli Donatısız Beton Yol</td>
<td>4,5 m</td>
<td>25 cm</td>
<td>35 yıl</td>
</tr>
<tr>
<td>KANADA</td>
<td>1993 AASHTO Tasarım Rehberi ve Kanada Çimento Birliği Mekanik-Ampirik Tasarım metodu</td>
<td>Derzli Donatısız Beton Yol ve Sürekli Donatılı Beton Yol</td>
<td>4 m</td>
<td>20 ile 28 cm</td>
<td>30 yıl</td>
</tr>
<tr>
<td>ALMANYA</td>
<td>Katalog *</td>
<td>Derzli Donatısız Beton Yol</td>
<td>5 m</td>
<td>26 cm</td>
<td>30 yıl</td>
</tr>
<tr>
<td>AVUSTURYA</td>
<td>Katalog *</td>
<td>Derzli Donatısız Beton Yol</td>
<td>5,5 m ile 6 m</td>
<td>20 cm</td>
<td>30 yıl</td>
</tr>
<tr>
<td>BELÇİKA</td>
<td>ABD’de kullanılan Sürekli Donatılı Beton Yol tasarım ve yapıp teknolojileri Belçika’ya uyarlanmış</td>
<td>Sürekli Donatılı Beton Yol</td>
<td>-</td>
<td>25 cm</td>
<td>40 yıl</td>
</tr>
<tr>
<td>HOLLANDA</td>
<td>Mekanik-Ampirik Tasarım metodu (Vencon programı)</td>
<td>Sürekli Donatılı Beton Yol ve Derzli Donatılı Beton Yol</td>
<td>-</td>
<td>25 cm</td>
<td>40 yıl</td>
</tr>
<tr>
<td>İNGİLTERE</td>
<td>Mekanik-Ampirik Tasarım metodu</td>
<td>Sürekli Donatılı Beton Yol</td>
<td>-</td>
<td>-</td>
<td>30 yıl</td>
</tr>
</tbody>
</table>

*Bu kataloglar ülkelerin uzun dönemlik malzeme, iklim ve trafik seviyesi tecrübeleri sonucunda oluşturulmuş olup, mekanik modellemeler, laboratuvar deneyleri ve saha gözlemleri ile kesitlerinثرlanması yapmıştır.
Tablo 2. Tipik derzli donatsız üstyapı tasarımları

(a) Kuzey Amerika

Tablo 3. Tipik sürekli donatılı üstyapı tasarlamaları

Beton yüzeyi yeterli sürünme ve kayma direncini sağlamak için çeşitli tekniklerle dokulandırılmaktadır. Ayrıca yüzey dokulandırılması ses oluşumunu da etkilediği için ülkeler arasında uygulanma farklılıklar gözlemlenmektedir. Tablo 5'te verilen ülkelerde kullanılan beton yüzeyi dokulandırma tekniklerinden en çok Avrupa ülkelerinde görülen yanmış olan görünür agregalı yüzey uygulamasının, ABD ve Kanada'da pek tercih edilmemesi, Hollanda'da ise 5 cm lik ince bir asfalt tabakası beton üzerine tercih edilmektedir.
### Tablo 4. Kayma donatısı kullanımı

<table>
<thead>
<tr>
<th>Ülke</th>
<th>Uygulanması</th>
<th>Kaplama Kalınlığı – Kayma Donatısı Çapi</th>
<th>Aralığı</th>
<th>Boyu</th>
<th>Kullanım Toleransi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ABD EYALETLERİ</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Florida</td>
<td>Metal kayma donatısı düzeniği</td>
<td>22 cm – 25 mm</td>
<td>30 cm</td>
<td>45 cm</td>
<td>Boyuna öteleme 5 cm Düsey öteleme 2.5 cm Dönme 1 cm</td>
</tr>
<tr>
<td></td>
<td>Selha düzeneği veya mekanik yerleştiriciler</td>
<td>17-19 cm – 25 mm</td>
<td>30 cm</td>
<td>45 cm</td>
<td>Boyuna öteleme 0.5 cm Düsey öteleme 0.5 cm Dönme 0.5 cm</td>
</tr>
<tr>
<td></td>
<td>Selha düzeneği veya mekanik yerleştiriciler</td>
<td>40 mm</td>
<td>30 cm</td>
<td>45 cm</td>
<td>Boyuna öteleme 1 cm Düsey öteleme 1 cm Dönme 1 cm</td>
</tr>
<tr>
<td></td>
<td>Otomatik kayma donatısı yerleştiricileri veya Sabitlenmiş sehpa metodu</td>
<td>Değişken</td>
<td>30 cm</td>
<td>45 cm</td>
<td>Boyuna öteleme 5 cm Düsey öteleme 2.5 cm Dönme 1 cm</td>
</tr>
<tr>
<td>Nevada</td>
<td>Plastik kaplamalı çelik kayma donatıları</td>
<td>25 mm</td>
<td>25 cm</td>
<td>50 cm</td>
<td>-</td>
</tr>
<tr>
<td>ALMANYA</td>
<td>Otomatik kayma donatısı yerleştiricileri</td>
<td>25 mm</td>
<td>Değişken</td>
<td>50 cm</td>
<td>-</td>
</tr>
<tr>
<td>AVUSTURYA</td>
<td>Epoksi veya bitümle kaplı kayma donatıları</td>
<td>25 mm</td>
<td>30 cm</td>
<td>60 cm</td>
<td>-</td>
</tr>
<tr>
<td>BELÇİKA</td>
<td>Telis Çekme Elmasla Taşlama</td>
<td>20 mm &lt; Oluk Derinliği &lt; 40 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOLLANDA</td>
<td>2006 dan önce, Boyuna Ağır Telis Çekme</td>
<td>2006 dan sonra, Görünür Agregalı Yüzey</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Tablo 5. Ülkelere göre Beton Üstü Doku Tipleri

<table>
<thead>
<tr>
<th>Ülke</th>
<th>Yüzey Dokulandırma Teknikleri</th>
<th>Standart Dokulandırma Oranları</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ABD EYALETLERİ</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Florida</td>
<td>Telis Çekme</td>
<td>20 mm &lt; Oluk Derinliği &lt; 40 mm</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Suni Çim Çekme</td>
<td>3 mm &lt; Tarak Derinliği &lt; 5 mm</td>
</tr>
<tr>
<td></td>
<td>Boyuna Taraklama</td>
<td>2 mm &lt; Tarak Genişliği &lt; 3 mm</td>
</tr>
<tr>
<td>Washington</td>
<td>Boyuna Taraklama</td>
<td>3 mm &lt; Tarak Derinliği &lt; 5 mm</td>
</tr>
<tr>
<td>Nevada</td>
<td>Telis Çekme</td>
<td>3 mm &lt; Tarak Derinliği &lt; 5 mm</td>
</tr>
<tr>
<td>KANADA</td>
<td>Boyuna Taraklama</td>
<td>2 mm &lt; Tarak Genişliği &lt; 3 mm</td>
</tr>
<tr>
<td>ALMANYA</td>
<td>2006 dan önce, Boyuna Ağır Telis Çekme</td>
<td>Agrega Boyutu &lt; 8 mm</td>
</tr>
<tr>
<td></td>
<td>2006 dan sonra, Görünür Agregalı Yüzey</td>
<td></td>
</tr>
<tr>
<td>AVUSTURYA</td>
<td>Görünür Agregalı Yüzey</td>
<td>Agrega Boyutu &lt; 8 mm</td>
</tr>
<tr>
<td>BELÇİKA</td>
<td>Görünür Agregalı Yüzey</td>
<td></td>
</tr>
<tr>
<td>HOLLANDA</td>
<td>Asfalt Kaplama</td>
<td></td>
</tr>
</tbody>
</table>

3 BETON KARIŞIM TASARIMI

Beton karışımında kullanılan bileşenlerden agrega ve çimento özellikleri ile beton karışımından beklenen temel gereksinimler Tablo 6'da özetlenmiştir. Tablodan da görüleceği üzere ABD'de gerek Avrupa standardlarına göre CEM.

Tablo 6. Şartnamelerde yeraal beton karışım tasarımına ilişkin veriler

<table>
<thead>
<tr>
<th>Ülke</th>
<th>Çimento Tipi</th>
<th>İri Agrega</th>
<th>Min. 28 gün basınç dayanımı</th>
<th>Maks. s/c oranı</th>
<th>Min. çimento dozajı</th>
<th>Hava İçeriği</th>
<th>Slamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABD EYALETLERİ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Florida</td>
<td>I,II,III IP ve IS</td>
<td>No.57, No.67, No.78</td>
<td>20 MPa</td>
<td>0.50</td>
<td>278 kg/m³</td>
<td>1.0 - 6.0 %</td>
<td>5 cm</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>I,II,III IP ve IS</td>
<td>AASHTO No.4 ve No.57</td>
<td>25 MPa</td>
<td>0.42</td>
<td>335 kg/m³</td>
<td>7.0 % ± 1.5</td>
<td>5 cm</td>
</tr>
<tr>
<td>Washington</td>
<td>I,II,III IP ve IS</td>
<td>AASHTO 467 maks. dane çapı 37.5 mm</td>
<td>27 MPa</td>
<td>0.44</td>
<td>335 kg/m³</td>
<td>5.5 % ± 2</td>
<td>-</td>
</tr>
<tr>
<td>Nevada</td>
<td>II, V ve IP</td>
<td>AASHTO No 57 maks. dane çapı 25 mm</td>
<td>27 MPa</td>
<td>0.47</td>
<td>362 kg/m³</td>
<td>5.0 % ± 1</td>
<td>2.5 cm - 7.5 cm</td>
</tr>
<tr>
<td>KANADA</td>
<td>-</td>
<td>Nominal maks. dane çapı 37.5-mm</td>
<td>30 MPa - Ontario 35 MPa - Quebec</td>
<td>-</td>
<td>-</td>
<td>6.0 % ± 1.5</td>
<td>NA</td>
</tr>
<tr>
<td>ALMANYA</td>
<td>Tipik olarak CEM I 32.5 R</td>
<td>Normal yapılarda kullanılan agregala kıyasla yüksek standardta agrega aranır</td>
<td>37 MPa</td>
<td>0.45</td>
<td>350 kg/m³</td>
<td>4.0 %</td>
<td>-</td>
</tr>
<tr>
<td>AVUSTURYA</td>
<td>Tipik olarak CEM I 32.5 R</td>
<td>-</td>
<td>Üst katmandan, 40 MPa Basınç 7 MPA Eğilme Dayanımı</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BELÇİKA</td>
<td>CEM I 42.5 CEM III /A 42.5 düşük alcali içerikli</td>
<td>maks. dane çapı 20 mm ve 32 mm, belirli bir gradasyon aranır</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HOLLANDA</td>
<td>CEM I 32.5 R, CEM II /B-V 32.5 R</td>
<td>C 35/45</td>
<td>0.55</td>
<td>320 kg/m³</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>İNGİLTERE</td>
<td>-</td>
<td>40 MPa</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Tablo 7. ABD eyaletleri şartnameselde yer alan mineral katkı maddeleri hakkında veriler

<table>
<thead>
<tr>
<th>ABD Eyalet</th>
<th>Silis Dumanı Şartname</th>
<th>Uçucu Kül Şartname</th>
<th>Cüruf Şartname</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida</td>
<td>ASTM C1240</td>
<td>Evet</td>
<td>Evet</td>
</tr>
<tr>
<td>Nevada</td>
<td>ASTM C1240</td>
<td>Hayar</td>
<td>Evet</td>
</tr>
<tr>
<td>Washington</td>
<td>AASHTO M307</td>
<td>Evet</td>
<td>Evet</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>AASHTO M307</td>
<td>Evet</td>
<td>Evet</td>
</tr>
<tr>
<td>CANADA</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ALMANYA</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BELÇİKA</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>AVUSTURYA</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HOLLANDA</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Ayrıca mineral katkı maddelerinin kullanımı ile ilgili özellikle ABD seçili eyaletlerine ait ayrıntılı bilgiler tablo 7 de verilmiştir. Genel olarak eyaletlerde silis dumanı kullanmayı arzımlık çimento miktarının % 10’u aşmadığı görülenin özellikle Florida eyaletinde cüruf kullanımının diğer eyaletlerden farklı olarak % 70’leri bulщуmuştur. Aynı şekilde uçucu kül için izin verilen miktar Florida eyaleti için diğer eyaletlere oranla daha yüksektir. Mineral katkı maddelerinin diğer ülkelerde kullanımı ABD kadar yaygın olmamasına rağmen Kanada’da % 25 uçucu kül ile silis dumanın kullanımını diğer ülkelere göre oldukça yüksek düzeydeki olmasına rağmen Almanya ve Belçika gibi Avrupa ülkelerinde kullanılırken, Kanada ve ABD eyaletleri şartnamelerinde CEMII/B-S ve CEMII/A şekilde kullanılmaktadır.

4 SONUÇLAR

Beton yol üstünlükler, esnek üstünlıklar göre dünya genelinde oldukça az tercih edilmesine rağmen özellikle ağır tonajlı yüksek trafik hacimlerine sahip yollarla sağlanmış olduğu avantajlı yaşam döngüsü maliyeti ve sürdürülebilir etkisi nedeniyle önemli bir konuma gelmektedir. Bundan dolayı özellikle gelişmiş ülkelerin birçoğu bu avantajdan faydalanmak için beton yolların yararlanmasını sağlar. ABD’de yoğun trafik hacimine sahip yolların birçoğunda, Kanada’nın Quebec eyaletinde ise beton yollar, tüm yolların % 4’üne tekbirıl etmesine rağmen trafiğin % 75’i karşılıyacak oranında tasarlanmıştır. Avrupa ülkelerinde ise özellikle Almanya, Avusturya ve Belçika gibi Avrupa ülkelerinde oldukça yaygın olarak kullanılmaktadır. Almanya’da yaklaşık % 75’i, Kanada’da % 60’da beton üstünlük tercih edilmektedir.

Beton yol üstünlüğü tercih eden ülkelerin önemli bir bölümü ABD’deki gibi belirli bir iklim veya iklim koşullarına sahip olan ülkelerdir. Tercih edilen çimento maddelerini belirlemek için, sonuçlar aşağıdaki tablonun verilerine dayanarak AASHTO ve ASTM standardlarında belirtilen kriterlere dayanarak belirlenmiştir. ALMANYA şartnamesi cimento miktarı % 50 ile % 30, Avusturya şartnamesi cimento miktarı %50 ile % 20 arasında, HOLLANDA şartnamesi cimento miktarı ise % 5 ile % 30 arasında belirlenmiştir.


REFERENCES

- WSDOT. (2011). Pavement Policy, Washington State Department, Environmental and Engineering Programs Division State Materials Laboratory Pavements Division, Olympia, 98504-7365.
- Austrian Association for Research on Road, Rail, and Transport, Guidelines and Specifications for Road Construction, RVS 88.06.32, February 2006 edition, English translation.
1. GİRİŞ

Kayma direnci, önemli bir üstyapı değerlendirme parametresidir. Yol yüzeyi kayma direnci değerlendirmeleri modern durumunun saptanması ve zaman göre değişimlerinin incelenerek değerlendirilmesi amaçlanmıştır.

Ülkenizde, farklı malzemelerle inşa edilen iki farklı kaplamanın kayma direnci açısından mevcut durumunun saptanması ve zaman göre değişimlerinin incelenerek değerlendirilmesi amaçlanmıştır.

Kayma direnci ölçümlerinde kullanılan malzeme ve karışım özellikleri, yol yüzey dokusunu belirleyen önemli faktörlere ve uzun vadede, trafik yükleri ve çevresel etkiler altında, agreganın cıhalanması, agreg ve karışımın aşınma karşısında gösterdığı direnç gösterebilme özellikleri doğrultusunda, yüzey dokusunun dayanımını etkiler (Hall et al. 2009).

2. KAYMA DİRENCİ VE YOL YÜZEY DOKUSU

2.1. Kayma Direnci


Kayma direnci her ne kadar kaplama ve malzeme özellikleri ile ilgili olarak düşünülse de, tekerlek ve kaplama arasında oluşan kuvveti etkileyen diğer faktörler de vardır. Kayma direnci pek çok parametreye bağlıdır (Ulliyhtz et al. 1998):
- Teker-kaplama temas yüzeyi
- Yüzey dokusu (Mikrodoku ve makrodoku)
- Hava şartları (Su film kalınlığı, sıcaklık, kar veya buz mevcudiyeti)
- Mevsim
- Kaplama tipi
- Yük
- Araç hızı
- Yüzey kirliği
- Lastik tipi ve dizaynı
- Lastik basınç

2.2. Yol Yüzey Dokusu


Şekil 1. Makrodoku ve mikrodoku kavramları örnekleri ile görülmektedir (Flintsch et. al. 2003)


Değişik hızlardaki araç trafiğinde yeterli bir kayma direncinin sağlanabilmesi için, yol yüzeyi, hem makro dokuya hem mikro dokuya sahip olmalıdır.
2.3. Kayma Direnci ve Ölçümleri

Genel olarak kayma direnci; sürtünme katsayısı (faktörü) veya kayma sayısı gibi sürtünme ölçüm yöntemlerinden biri ile ölçülür.

Yol kaplaması sürtünme direnci çoğunlukla ASTM E-274 metoduna uygun olarak ölçülen Kayma Sayısı [Skid Number (SN)] ile ifade edilmektedir (Smith, 1977).

Kayma Sayısı (SN) aşağıdaki formülle belirlenir (ASTM E 274):

\[ SN = \frac{F}{W} \times 100 \]  

SN = Kayma Sayısı SN  
F = Çekme kuvveti (Lastik ile kaplamanın temas ettiği alanda deney lastığını uygulanan yatay kuvvet, lbf veya N)  
W = Deney lastığı üzerindeki dinamik yük (lbf veya N)

Kayma Sayısı; kaplamayı sürtünme test sonuçlarının raporlanmasıında kullanılan sayıdır. 0-100 arasında değişir. 0’a yaklaştıkça yol güvenliği açısından önemli olan kayma karşı direncin kötü olduğu, 100’e yaklaştırıldığında kayma karşı direncin iyi olduğu görülmektedir.

3. METOD VE METODOLOJİ

3.1 Kayma Sayısı ölçümleri

Yapılan çalışmada kaplama sürtünme direnci diğer bir deyişle kayma sayısı, kaplama-lastik arasındaki sürtünme ile ilgili mikro ve makro doku özelliklerinin ölçümü ile belirlenmiştir.

Kaplama yüzeyi sürtünme direnci ölçümünde Sürtünme Ölçüm Cihazı (Friction Tester) kullanılarak ASTM E 274 standardına uygun ölçümler yapılmış, ölçümlerde ASTM E-501 standardında özel ölçüm lastikleri kullanılmış ve kayma sayısı değerleri tespit edilmiştir.

Kayma sayısı; aracın, 65 km/saat (±1 km/saat) hızla gidişi sırasında test lastığıne belirli kalınlık (0,5 mm) oluşturacak miktarında su püskürterek uygun frenleme yapmak suretiyle tekerenin kilitlenip yol yüzeyi üzerinde kayması sonucunda ölçülmüştür. Sürtünme Ölçüm Cihazı Şekil 2 de verilmiştir.
Şekil 2: Sürtünme Ölçüm Cihazı (Friction Tester)

Asfalt kaplama yüzeyine ait kayma sayısı değerleri proje veya KKNo vb. belirli noktalardan başlayarak, ardışık olarak, minimum 200 m ve üzeri mesafe aralıklarında ölçülmiştir.

3.2. Veri analizi ve değerlendirme kriterleri:

Ölçüm verileri, bilgisayar analiz programları ile analiz edilerek homojen kesimler belirlenmiştir. Karayollarında uygulanan Sürtünme Direnci Kriterleri Tablo 1 de verilmiştir. Ölçülüp, toplanan veriler bu kriterler doğrultusunda değerlendirilmiştir.

Tablo 1: Sürtünme direnci kriterleri

<table>
<thead>
<tr>
<th>Sürtünme Direnci Değeri (Kayma Sayısı /Skid Number = SN)</th>
<th>Sürtünme Derecesi</th>
<th>SN Değerlerine Göre Yapılması Gerekenler</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 46</td>
<td>İyi</td>
<td>Kaymaya karşı direnci iyi</td>
</tr>
<tr>
<td>45-30</td>
<td>Orta</td>
<td>Kaplama sık sık izlenmeli</td>
</tr>
<tr>
<td>&lt; 30</td>
<td>Kötü</td>
<td>Düzeltici önlem alınmalı (Yüzey pürüzlendirilmeli)</td>
</tr>
</tbody>
</table>

4. ELDE EDİLEN VERİ VE DEĞERLENDİRMELER


Ölçüm sonuçları, kayma direnci açısından, SN değerleri değişim oranlarının, %50 Bazalt+%50 Kalker +Modifiye Bitüm (MB) ile yapılan kaplamada %18 ile %30 arasında, Granodiyonit+normal bitüm (NB) ile yapılan kaplamada ise %5 ile %17 arasında olduğunu göstermiştir. Granodiyonit+NB ile yapılan kesimlerin YOGT değerleri daha yüksek olmasına rağmen, %50 Bazalt+%50 Kalker+MB ile yapılan kesimlere oranla, zamana karşı SN değerlerindeki düşmelerin daha az olduğunu gözlemmiştir Tablo 2. SN değişim oranlarına ilişkin grafik Şekil 3 de verilmiştir.

Bu sonuçlar, yol yapımında kullanılabilecek malzemelerin, kaplamaların seçiminde, mevcut kaplamaların bakım-onarım ve rehabilitasyonunda verilecek kararlar için değerli olacaktır. Ayrıca, ÜYS kapsamında diğer performans kriterleri ile birlikte değerlendirilerek, teknik verilere dayalı ve bilimsel yöntemlerle, fayda/maliyet analizleri doğrultusunda güvenli, ekonomik ve uzun ömürlü yolların hizmete sunulmasını sağlayacaktır.
Tablo 2. Ölçülen Kayma Sayısı değerlendirilmeleri.

<table>
<thead>
<tr>
<th>Bl. Md.</th>
<th>KKNo, Yol Adı</th>
<th>Kaplama, ve Mlz. Bilgiler</th>
<th>İlk Ölçümler</th>
<th>Son Ölçümler</th>
<th>Yönü, Şeridi</th>
<th>Değişim Oranı %</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.</td>
<td>010-18 Ordu km ~ 12+000-13+755</td>
<td>MB Aşınma ~%50Kalker+ %50 Bazalt</td>
<td>2-7.06.2008</td>
<td>55</td>
<td>26.03.2014</td>
<td>45</td>
</tr>
<tr>
<td>7.</td>
<td>010-18 Ordu Nefise AKÇELİK Tüneli 3.820 km km ~ 13+755 - 17+575</td>
<td>MB Aşınma ~%50Kalker+ %50 Bazalt</td>
<td>2-7.06.2008</td>
<td>57</td>
<td>26.03.2014</td>
<td>40</td>
</tr>
</tbody>
</table>

Tablo 2. Ölçülen kesimlerin YOGT değerleri.

<table>
<thead>
<tr>
<th>Kaplama Tipi</th>
<th>Ölçülen Kesimler</th>
<th>YOGT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2008</td>
</tr>
<tr>
<td>MB Aşınma ~%50 Kalker+ %50 Bazalt</td>
<td>KY.7.BL.MD. KKNo:010-18 Ordu km:12+000-13+755 (2. Dilm)</td>
<td>8688</td>
</tr>
<tr>
<td></td>
<td></td>
<td>km:13+755-17+575 (Tünel)(2. Dlm)</td>
</tr>
<tr>
<td>NB Aşınma Granodiyonit Agregası</td>
<td>KY.10.BL.MD. KKNo:010-19 Bulancak km:0+000-10+000 (1. Dilm)</td>
<td>10212</td>
</tr>
<tr>
<td></td>
<td></td>
<td>km:10+000-11+600 (2. Dilm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>km:11+600-15+000 (2. Dilm)</td>
</tr>
</tbody>
</table>
Şekil 2: 2008 ve 2014 yılları kayma sayısı değerlendirmeleri

Şekil 3: 2008 ve 2014 yılları arası kayma sayısı % değişimleri
5. SONUÇLAR

Yeni yapılan, farklı malzeme ve farklı dizaynlarla imal edilen 2 farklı kaplamının (%50 Bazalt+%50 Kalker+MB aşınma ve Granodiyonit+NB aşınma) 7 ayrı kesimde sürünme direnci değerleri belirlenmiş ve zamana göre değişiklikler incelenerek karşılaştırılmıştır. Ancak, hemen hemen aynı iklim koşullarında yer alan farklı malzeme ve dizaynlarla imal edilen kaplama tiplerine ait SN değerleri, ilerleyen zamana göre değişiklikler göstermiştir.

Yapılan çalışmalar sonucunda:

➢ %50 Bazalt+%50 Kalker+MB ve Granodiyonit+NB ile yapılan 2 ayrı kaplamının, imal tarihlerinde SN değerlerinin 54 - 57 arasında, birbirlerine çok yakın değerler aldığını,

➢ Her iki kaplama tipinde, 2008 ve 2014 yılları itibariyle ölçülen SN değerlerinin ilerleyen zamanına göre değişiklikler göstermekle beraber aranan şartname değerlerini sağladığı,

➢ Kaplamanın 6 yıllık hizmet süresi sonrası SN değerlerinin zamana göre değişimlerinin (azalma oranlarının); %50 Bazalt+%50 Kalker+MB ile yapılanlarda daha fazla olduğu ve % 20 ile %30 arasında değerler aldığı,
Granodiyonit+NB ile yapılanlarda ise daha az ve % 5 ile %17 arasında olup daha iyi sonuç verdiği,

➢ Granodiyonit+NB ile yapılan kesimlerdeki YOGT değerlerinin daha yüksek olması rağmen, %50 Bazalt+%50 Kalker+MB ile yapılan kesimlerdeki kayma direncinden daha iyi performans gösterdiği,

➢ Kaplamanın kayma direncine; agrega, bağlayıcı ve karışım dizaynının önemli ölçüde etki ettiği,

Tespit edilmiştir.

Yolların SN değerleri, aynı zamanda Üstyapı Yönetim Sistemi çalışmalarının da önemli bir kısmını oluşturmustur. Yeni yapılan ve daha sonra periyodik olarak izlenen kaplamalardaki SN değerlerinin belirlendiği bu çalışmalar doğrultusunda; farklı malzeme ve dizaynlarla yapılan farklı kaplama tiplerinde, hizmet süreleri boyunca kayma dirençleri izlenecek ve performans modelleri oluşturulacaktır. Bu veriler, karayollarında kayma direncinin yönetimi ve yeni yüzey kaplamalarının dizayn üzerine olan önemli bilgi ve ayrıntıları ortaya koyarak gerekli bakım-yonarım, takviye veya yeniden yapım alternatiflerinin seçilime temel oluşturacaktır.

KAYNAKLAR


FEHRL Report 2006/01 HERMES project, Harmonization of European routine and research measuring equipment for skid resistance.


Kireçtaşının Taş Mastik Asfalt Tabakasında Agrega Olarak Kullanımının Araştırılması

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² Karayolları 6. Bölge Müdürlüğü, Ar-Ge Başmühendisliği, Kayseri, Türkiye
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ÖZET

Ülkemizde son yıllarda demiryolu, hava yolu gibi ulaştırma alternatiflerinin gelişmiş olması rağmen halen yolcu taşımacılığının %90’ı ve yük taşımacılığının yaklaşık %78’i karayolları üzerinden gerçekleşmektedir. Noktalar arasında kesintisiz taşımaya imkan vermesi, ayrıca esnek yapısı, hızı ve modlar arasında geçişlere uyumlu olması, beklenen genişleme katkı sağlayacak konfor ve zaman kazancı, trafiğin güvencesi, iç ve dış turizme getireceği yarar, ulusal güvenliği, diğer ulaşım türleri ile bütünüyle ulusal ve uluslararası bağlantıların parçası olma gibi birçok kriter göz önünde bulunduğunda, karayolu ulaşımının giderek daha da gelişme gösterceği aşikardır.

Bununla birlikte yollarımızda; artan trafik hacmi, aşırı yükleme, iklim, topoğrafya ve yapım koşullarından gelen olumsuz etkiler de eklendiğinde yorulma, tekerlek izi oluşumu ve ondülasyon gibi bozulmalar meydana gelmektedir. Sıcak iklim koşullarında ve ağır trafik yükleri altında oluşabilecek kalıcı deformasyonlar karşı sert ve dayanıklı magmatik kayaçların agrega olarak kullanıldığı Taş Mastik Asfalt (TMA) karışımları yüksek dayanım göstermektedir. Bu açıdan TMA kullanımı, kaplama işlemcinin performansını arttırır ve son yıllarda karayollarında kullanımı yaygınlaşmaya başlamıştır.

Bu nedenle; şartname kriterleri bakımından uygun magmatik kaya temin edilemeyen bölgelerde, alternatif olabilecek kireçtaşı agregaları ile hazırlanan TMA karışımının özelikleri belirlenmiştir. Sert ve dayanıklı magmatik kayaçlar ile hazırlanan TMA karışımı ile kireçtaşı agregaları ile hazırlanan TMA karışımını karşılaştırılmıştır. Bu çalışma ile hazırlanan TMA karışımları üzerinde; plasik deformasyonlarla karşı davranış tekterle izinde oturma (TIO) ve sudan kaynaklanan bozulmalara karşı dayanım belirleyen İndirekt Çekme Mukavemeti (İÇM) deneyleri yürütülmüştür.

Anahtar Sözcükler: Taş Mastik Asfalt, Bitüm Süzülme, Tekerlek İzinde Oturma

1. GİRİŞ


TMA aşınma karışımlarında kaba agrega olarak granit, bazalt veya diğer magmatik kayaçların kirlenmesi, egzersiz ve diğer magmatik kayaçların kirlenmesinde elde edilen agregaların kullanılışı zorunlu olmaktadır. Ancak ülkemizde bu tür magmatik kayaçların her örneğinde istenen kalitede temin edilmiş jeolojik olarak mümkün olamaz.
İstenilen kalitede magmatik kayaçların bulunduğu bölgelerde ise taşıma mesafeleri, TMA karışımlarının maliyetini önemli ölçüde etkilemektedir ve artmaktadır.

Bilindiği üzere birçok bölgesinde Karayolları Teknik Şartnamesi (KTŞ) kriterleri bakımdan, cıalanma değeri dışında diğer tüm vasıfları sağlayan kaliteli kalker ocakları bulunmaktadır. Bu ocaklardan üretilen agregalar birçok yol ağımızda BSK aşınma karışımı olarak kullanılmaktadır.

Bu çalışma, TMA karışımlarda kalker agregalarının kullanılmasının karışımın performans değerlerine üzerindeki etkisini belirlemek amacıyla yürütülmüştür.

- Bağlı bulunan bölge sınırları içerisinde agrega ocakları incelenmek ve fiziksel deneyleri yapılmak suretiyle çalışmaya esas teşkil eden Kalker ve Bazalt agregaları belirlenmiştir.
- Belirlenen Kalker ve Bazalt agrega ile ayrı ayrı modifiye bitümlü Marshall karışımları hazırlanmıştır.
- Optimum bitüm ve hazırlanan briketlere İndirekt Çekme Mukavemeti (İÇM), Schellenberger Bitüm Sızülme Deneyi ve TİO deneyleri yapılmıştır.

2. MALZEME ÖZELLİKLERİ

2.1. Agrega Özellikleri ve Gradasyonlar

Çalışmada, Kayseri civarında bulunan Kamber Kalker ve Nevşehir civarında bulunan Karayazı Bazalt Taş Ocaklarının üretilen agregalar ile Taş Mastik Asfalt gradasyon limitlerine uygun agregat karışım gradasyonu kullanılmıştır. Agregaların özellikleri ve karışım gradasyonları Tablo-1 ve 2’de verilmiştir.

Kalker agrega ile yapılan çalışmalarla Karayolları Teknik Şartnamesi Tip-1B, Bazalt agregalarla yapılan çalışmalarla ise Tip-1A karışım gradasyonu şartnamesi kullanılmıştır. Kalker agrega ile yapılan bir diğer çalışmada ise Tip-1B şartname alt limitlerinde karışım dizaynı hazırlanmıştır.
Şekil 1. Kalker Agreagli TMA Tip-1B Karışım Gradasyonu

Şekil 2. Kalker Agreagli TMA Tip-1B Şartname Alt Limit Karışım Gradasyonu

Şekil 3. Bazalt Agreagli TMA Tip-1A Karışım Gradasyonu
2.2. Bitümlü Bağlayıcı

Proje çalışmalarında PMB 70-22 sınıfı modifiye bitüm kullanılmış olup, modifiye bitüme yapılan deneylere ait sonuçlar aşağıda verilmiştir.

Tablo-3. PMB 70-22 Özellikleri

<table>
<thead>
<tr>
<th>DENEY ADI</th>
<th>SONUÇLAR</th>
<th>PMB Şartnamesi 70-22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetrasyon, 0,1 mm</td>
<td>41</td>
<td>30-90</td>
</tr>
<tr>
<td>Yumuşama Noktası, °C</td>
<td>57,4</td>
<td>Min.62</td>
</tr>
<tr>
<td>Elastik Geri Dönme, %</td>
<td>76,5</td>
<td></td>
</tr>
<tr>
<td>Parlama Noktası, °C</td>
<td>280</td>
<td>Min.220</td>
</tr>
<tr>
<td>Öğül Ağırlığı, g/cm³</td>
<td>1,031</td>
<td>1.0-1.1</td>
</tr>
<tr>
<td>DEMPOMA STABİLİTESİ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yumuşama Noktası Farkı, °C</td>
<td>14,8</td>
<td>Mak.5</td>
</tr>
<tr>
<td>Penetrasyon Farkı, 0,1 mm</td>
<td>9,0</td>
<td>Mak.12</td>
</tr>
<tr>
<td>Dinamik Kesme Reometresi (DSR), °C</td>
<td>76,5</td>
<td>Min.70</td>
</tr>
<tr>
<td>DONMELİ İNCE FİLM ETÜVÜ DENEYİ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kütle Kaybı, %</td>
<td>0,06</td>
<td>Mak.1.0</td>
</tr>
<tr>
<td>Yumuşama Noktası, °C</td>
<td>64,2</td>
<td>Min.60</td>
</tr>
<tr>
<td>Yumuşama Noktasındaki Değişiklik</td>
<td></td>
<td></td>
</tr>
<tr>
<td>artma</td>
<td>6,8</td>
<td>Mak.8</td>
</tr>
<tr>
<td>azalma</td>
<td>-</td>
<td>Msk.5</td>
</tr>
<tr>
<td>Kalker Penetrasyon</td>
<td>70,7</td>
<td>Min.50</td>
</tr>
<tr>
<td>Dinamik Kesme Reometresi (DSR), °C</td>
<td>77,9</td>
<td>Min.70</td>
</tr>
<tr>
<td>RTFOT+PAV İle Yaşlandırılmış Modifiye Bitüme Yapılan Deneyler</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSR</td>
<td>24,4</td>
<td>Mak.28</td>
</tr>
<tr>
<td>Kiriş Eğme Reometresi</td>
<td>-12</td>
<td>Mak.-12</td>
</tr>
</tbody>
</table>

3. YAPILAN ÇALIŞMALAR

3.1. Karışım Dizaynları

Marshall Karışım Dizayn yöntemi ile yukarıda verilen gradasyonlarda PMB 70-22 ile Kalker ve Bazalt agregalar ile hazırlanan karışım dizaynlarının değerleri Tablo-4 ’de verilmiştir.

Tablo-4 Dizayn Değerleri

<table>
<thead>
<tr>
<th></th>
<th>Kalker Agregalı (Kamber Taş Ocağı)</th>
<th>Kalker Agregalı (Kamber Taş Ocağı) (Tip-1B Şartname Alt Limit)</th>
<th>Bazalt Agregalı (Karayazı Taş Ocağı)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitüm, %</td>
<td>5,80</td>
<td>6,50</td>
<td>6,85</td>
</tr>
<tr>
<td>Hacim Özgül Ağırlığı</td>
<td>2,415</td>
<td>2,390</td>
<td>2,445</td>
</tr>
<tr>
<td>Maks. Teo. Özgül Ağırlığı</td>
<td>2,471</td>
<td>2,453</td>
<td>2,523</td>
</tr>
<tr>
<td>Hava Boşluğu, %</td>
<td>2,25</td>
<td>2,57</td>
<td>3,07</td>
</tr>
<tr>
<td>VMA, %</td>
<td>14,3</td>
<td>16,1</td>
<td>16,1</td>
</tr>
<tr>
<td>Asfalt Dolu Boşluk</td>
<td>84,3</td>
<td>83,9</td>
<td>80,9</td>
</tr>
</tbody>
</table>
3.2. Yapılan Deneyler

Orta gradasyonlu Kalker agreg ve Bazalt agreg için optimum bitüm değerlerinde briketler hazırlanarak TİO, Indirekt Çekme Mukavemeti (İÇM), Schellenberger Bitüm Süzülme Deneyleri gerçekleştirilmiştir.

3.2.1. Karışmaların Su Hasarına Karşı Mukavemeti


Şekil 5. Karışmaların İndirekt Çekme Mukavemeti Oranı.
3.2.2. Schellenberger Bitüm Süzülme Deneyi (TS EN 12697-18)

Schellenberger Bitüm Süzülme Deneyinde, modifiye bitümlü karışımlar (PMB) için 145 ± 5 °C’de hazırlanılan 1.000 g TMA karışımı 1.000 ml’lik önceden 110 °C’lik etüvde 15 dakika ısıtılmış cam behere konularak 0,1 g hassasiyetinde tartılır. Beher, üzeri kapatıldıktan sonra 1 saat ± 1 dk süre ile 185 °C sıcaklıkta etüvde bekletilir. Bu sürenin sonunda etüvden çıkarılarak ve karışım beheri sarsmadan boşaltılır. Boşaltılan karışım 0,1 g hassasiyetinde tartılır ve ağırlık kaybı yüzde olarak hesaplanır. Deney 3 paralel karışım numunesi ile yapılarak sonuçların ortalaması alınır. Süzülmeyen sonra kalan malzemenin KTŞ kriterlerine göre %0,3’ten fazla olması gerekmektedir.

![Schellenberger Bitüm Süzülme Deneyi](image)


3.2.3. Tekerlek İzinde Oturma Deneyi

Tekerlek izinde oturma deneyinde, yukarıda ifade edilen bitüm yüzdelerinde Kalker ve Bazalt agrega ile PMB 70-22 sınıfı modifiye bitüm kullanılarak hazırlanan dizayn karışımına TS EN 12697-22 standardına göre Hamburg tekerlek izinde oturma deneyi yapılmış ve TİO yüzdeleri bulunmaktadır. Deneyler 32cm x 26cm x 5cm boyutlarında prizmatik numunelere kuru metoda göre 60 °C sıcaklıkta yapılmıştır. Deney sonuçları aşağıda verilmiştir.

![Tekerlek İzinde Oturma Deneyi](image)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Rut depth [mm]</th>
<th>Average value [mm]</th>
<th>range [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>2.29</td>
<td>2.52</td>
<td>0.45</td>
</tr>
<tr>
<td>Right</td>
<td>2.74</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Tekerlek İzinde Oturma Deneyi](image)


Yukarıda verilen Hamburg tipi tekerlek izinde oturma deneyi sonuçlarına göre kalkerli agrega ile yapılan TMA karışımına ait TİO deney sonucunun (%4.1) da Karayolları Teknik Şartnamesi kriterlerini (≤6%) sağladığı ve bazalt aggregalı karışımın TİO değerinden sadece %0,9 daha fazla olduğu tespit edilmiştir.

4. SONUÇLARIN DEĞERLENDİRİLMESİ


- Koşullandırma sonucu İÇM değerlerinde, Kalker agrega ile hazırlanan karışımlarda, Bazalt aggregalı karışımlara göre daha az düşüş olmuştur.
- Schellenberger Bitümm Sızılıme Deneyleri için, Kalker aggregalı ve Bazalt aggregalı karışımlarda şartname limitleri sağlanmıştır.
- Bazalt aggregalı karışımlarda TİO miktarları, Kalker aggregalı karışımlara göre daha az oluşmuştur.
- Kalker aggregalı karışımlarda oluşan TİO miktarları, Karayolları Teknik Şartnamesi limitleri içerisinde kalmıştır.
- Kalker aggregalı karışımlarda TMA Tip-1B için VMA değerleri, Bazalt aggregalı karışım Tip-1A ‘ya göre daha düşük ve şartname limitlerinin altında kalmıştır. Ancak TMA Tip-1B şartnamesi alt limitlerinde hazırlanan kalker aggregalı karışımlarda VMA değerinin şartname kriterlerini sağladığı görülmüştür.
- Kalker aggregalı karışımlarda, Bazalt aggregalı karışımlara göre daha düşük optimum bitüm yüzdeleri elde edilmiştir.

Sonuç olarak; Bazalt aggregalı karışımların plastik deformasyonlara karşı dayanımının daha yüksek olduğu TİO değerlерinden anlaşılmaktadır. Kalker aggregalı ile hazırlanan karışımların plastik deformasyon karşı dayanımının Bazalt aggregalıla hazırlanımiş karışımlara göre daha düşük olmasıın karışı şartname
limitleri içerisinde kaldıgı ve büyük bir farkın olmadığını görülmüştür. Kalker agregaları ile hazırlanan şartname gradasyonu toleransları içerisindeki karışımlarda VMA değerlerinin şartname limitlerinin altında kaldığı görülmüştür. Ancak Kalker agregalarla şartname gradasyonu alt limitlerinde hazırlanan karışımlarda ise VMA değerinin şartname limitlerini sağladığı görülmüştür. İÇM değerinde Bazalt agregalı karışımlarda ve Kalker agregalı karışımlarda şartname limitlerinin sağlandığı, bitüm süzülme deneylerinde de şartname limitlerinin sağlamıldığı anlaşılmıştır.

Tüm bu sonuçlar birlikte değerlendirildiğinde plastik deformasyonlar anlamında olumlu sonuç veren Kalker agregaları ile TMA imalatının yapılabilmesi, VMA değerleri için gradasyon limitlerinin düzenlenebileceği ya da plastik deformasyon görülmemiş ve VMA değeri şartname değerlerini sağlamayan Kalker agregaları için ayı bir VMA kriterinin oluşturulmasına mümkün olabileceğini anlamaktadır. Kalker agregaları ile hazırlanacak TMA karışımları, Bazalt bulunamayan birçok bölgede plastik deformasyonun önüne geçilebileceği gibi, nakliye mesafesi uzak olan bölgelerde de Kalker agregası kullanılarak TMA tabakası için ekonomiklik sağlanmış olacaktır.

KAYNAKLAR


Türkiye Üstyapı Yönetim Sistemi Geliştirme Çalışmaları

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ÖZET


Anahtar Sözcükler: Karayolu Üst Yapısı, Üstyapı Yönetim Sistemi

1. GİRİŞ

Karayolu ağları Ülkemizde en yaygın olarak kullanılan ulaşım ağlarından biridir. Karayolu ağlarındaki güvende ve konforu sağlayan en önemli unsur ise yol üst yapısı olarak görülmektedir. Ülkemizde son yıllarda gelişmeler paralel olarak karayolu ihtiyaç ve dolayısıyla bunu karşılamak için karayolu yapımı alanları artırılmaktadır. KGM sorumluluğunda mevcut 65.090 km yol ağının (BSK) yaklaşık 44.277 km (Bitümlü Sıcak Karışım) olarak hizmet vermektedir (www.kgm.gov.tr). Gerçekle seyahat, sürüş konforu ve taşın işleme giderlerinin düzenlenmesi nedeniyle Ülkemizde son yıllarda BSK yapımına yüksek derecede önem verilmiştir ve 2013 yılı EAPA verilerine göre Türkiye asfalt üretiminde 46,2 milyon ton ile Avrupa’dan birinci sırada yer almaktadır. KGM inranet üzerinden web tabanlı olarak tasarlanan bu sistem içerisinde; envanter veritabanı, performans ölçüm analizleri, bakım – onarım alternatiflerinin belirlenmesi ve bu alternatiflerin fa­ya/maliyet analizleri, a principio bakım – onarım öncelikleri modülü oluşturulmuştur. Bu çalışmada; 2009 yılından itibaren kadar hazırlanan “Türkiye Üstyapı Yönetim Sistemi” nin önemi ve özellikleri; 200-10, 200-11 ve 200-12 Nolu Devlet Yolu ÜYS değerlendirmeleri ile detaylandırılmaktadır.


Yollardaki bakım – onarım ihtiyaçlarının doğru şekilde belirlenip doğru zamanda yapılabilmesi için, bölgesel ve ülke yollarında bir Üstyapı Yönetim Sistemi (ÜYS) kurulması zorunludur. Yol ağında bulunan tüm yollardan düzenli aralıklarda toplanan verilerin analiz edilmesi ve bu değerlendirmelerin rutin gözlemler ile birleştirilmesi sonucunda, a princípio yakarının daha programlı ve ekonomik kullanılarak sağlanacaktır. Üstyapı Yönetim Sistemleri genel prensiplerini yanı sıra yerel şartlar itibari ile de analiz ve değerlendirmeleri ihtiyaç duyan sistemlerdir. Bu nedenle Üstyapı Yönetim Sistemi Geliştirilmesi çalışmalarını kapsayacak şekilde Türkiye geneli BSK kaplamalı yolların ait Defleksiyon, Uluslararası Düzgünsüzlük İndeksi (IRI), Tekerlek İzinde Oturma (TIO), üstyapı bozulmaları ve üstyapı makro dokusu gibi üstyapı bilgileri analiz edilmesi planlanmakta.
derlenerek üstüapıların mevcut durumu ortaya konmuş, mevcut durum değerlendirilerek gerekli kesimlerde uygun iyileştirme stratejilerinde karşılıştırma, mevcut durum değerlendirmeye teknikleriyle en uygun olanı belirlenmiştir. Ayrıca, hazırlanmış üstüapı planlamaları ile ilgili olan esgelerin için belirlenen bakım-onarım programları, teknik ve malı açıdan değerlendirilerek önerilerek ve bakım-onarım periyotları belirlenecektir. Bu aşamada, yollarda görülen bozulmaların tahlününe göz önünde bulundurularak yollar içerisinde yapılan planlanan yatırmalar belirlenerek, bütçe dağılımda parametre olarak kullanılacaktır.

2. ÜSTÜAP İ YÖNETİM SİSTEMİ KAVRİAİ


Üstüapı Yönetim Sistemi yol üstüapılarının belirli bir seviyede hizmet verebileceğini ve bunun korunmasını sağlamak üzere, sınırlı mevcut bir bütçeye en yüksek kazanç sağlayacak, en elverişli, en iyi stratejiler bulmak ve optimum bakım/onarım önlemlerini oluşturmak için saptanması için nesnel ve sistematisik yaklaşım sağlayan, bilgisayar destekli bir yönetim sistemidir.

Şekil 1. Üstüapı Performansı ve Bakım-Onarım Maliyeti İlişkisi


3. TÜRKİYE’DE ÜSTÜAP İ YÖNETİM SİSTEMİ ÇALIŞMALARI

göz önünde bulundurulacak olursa bakım-onarım maliyetleri de gün geçtikte artmaya devam edecektir. Yapılan yüksek harcamaların en uygun şekilde değerlendirilmesi için Karayolları Genel Müdürlüğü tarafından Türkiye’ye özgü bir Üst İprü Yönetimi Sistemi kurulması çalışmalarına başlanmıştır.


Üst İprü Yönetimi Sistemleri üç ana aşamadan oluşmaktadır.
1. Veritabanı oluşturulması
2. Ağ Düzeyinde Üst İprü Yönetimi
3. Proje Düzeyinde Üst İprü Yönetimi


3.1. Yol Üst İprü Ölçüm Çalışmaları


Şekil 2. Karayolları Genel Müdürlüğü Üst İprü Ölçüm Cihazları

Karayolları Genel Müdürlüğü bünyesinde bulunan cihazlar aşağıda açıklanmıştır.
- 1 Adet Dynatest RSP Mk-III Profilometre – OBSI Yüzey Gürültü conseg Ölçüm Cihazı (17 Lazer, 2 Akselerometre, 1 Atalet Hareket Sensörü, GPS, Mesafe Ölçer, OBSI Sistemi, Ortam ve Kaplama Sıcaklığı Ölçer)
- 13 Adet Dynatest RSP Mk-IV Profilometre (2 Lazer, 2 Akselerometre, GPS, Mesafe Ölçer)
- 1 Adet Dynatest 1295 Yol Üst İprü Sürünme Ölçüm Cihazı (1000 Lt. Su Tankı, 2 Adet Tam Frenleme Sistemi, GPS, Mesafe Ölçer, Ortam ve Kaplama Sıcaklığı Ölçer)
- 1 Adet Kuab Düşen Ağırlıklı Deflektometre Ölçüm Cihazı (9 Adet Jeofon, Mesafe Ölçer, Kaplama Sıcaklığı Ölçer)

652
Karayolları Genel Müdürlüğü bünyesinde bulunan 13 Adet Dynatest RSP Mk-IV Profilometre Ölçüm Cihazı 13 farklı Bölge Müdürlüğü'nde ödeme esas ölçümlerin yapılması amacıyla kullanılmaktadır. Bu cihazlar aynı zamanda Karayolları Genel Müdürlüğü'nde bulunan cihazlar ile birlikte Üst yapı Yönetim Sistemi Performans Durum Ölçümleri için de kullanılmaktadır.

Üst Yapı Yönetim Sistemi Geliştirilmesi kapsamında toplamda Türkiye genelinde 8362,69 km BSK yolunda performans ölçümleri tamamlanmış, analiz ve değerlendirme sonuçlarında raporlanmıştır. Yapılan tüm bu ölçümler boyunca tüm cihazların kalibrasyonları düzenli olarak yapılmış ve tüm arazi kontrollerine dikkat edilmiştir.

3.2. Analiz ve Değerlendirmeler

Yapılan ölçümler sonucu elde edilen veriler analiz edilmiştir ve sonuç değerleri ile yapısal ve fonksiyonel mevcut durum saptanmıştır. Tüm Türkiye genelinde yapılan bu analiz ve değerlendirme yöntemleri Ankara – Polatlı kesimini kapsayan 200-12 Kontrol Kesim Numarası yola ait örnekler ile aşağıda açıklanmıştır.

3.2.1. Düzgünsüzlük (IRI) Analizleri

Profilometre Ölçüm Cihazı ile ölçümler tamamlanan kesimde elde edilen IRI değerleri aşağıda belirtilen kriterler doğrultusunda sınıflandırılmıştır.

<table>
<thead>
<tr>
<th>Düzgünsüzlük Değeri (IRI - m/km)</th>
<th>Düzgünsüzlük Sınıflaması</th>
<th>Öncelik Sınıfı</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Mutlak Mükemmel</td>
<td></td>
</tr>
<tr>
<td>0 - 0.71</td>
<td>Çok İyi</td>
<td>6</td>
</tr>
<tr>
<td>0.72 - 1.11</td>
<td>İyi</td>
<td>5</td>
</tr>
<tr>
<td>1.12 - 1.58</td>
<td>Orta - İyi</td>
<td>4</td>
</tr>
<tr>
<td>1.59 - 1.80</td>
<td>Orta</td>
<td>3</td>
</tr>
<tr>
<td>1.81 - 2.13</td>
<td>kötü</td>
<td>2</td>
</tr>
<tr>
<td>&gt; 2.13</td>
<td>Çok Kötü</td>
<td>1</td>
</tr>
</tbody>
</table>

IRI Analiz sonuçlarında, öncelikle IRI değerlerine bağlı bozulma şiddetti sınıflandırmalarında, IRI’nin yükselmesi etken olan nedenler üzerinde durulmuştur. Yol Envanter Bilgileri, yüzey bozulma şiddeti ve konumları ile Üst yapı Puanlamasına esas yüzey bozulma analizleri sonuçları incelemiştir, IRI şiddetlerinin, yol fiziksel durum ile yakın ilişkisi olduğu saptanmıştır.

IRI değerlendirme çalışmaları, 20 m aralıklarla yapılan IRI ölçümlerinin küçük miktarda sapmalara göz ardı ederek oluşturulmuş göreceli olarak uzun homojen kesimler oluşturularak yapılmıştır. Tüm bu değerlendirmenin sonuçunda Ankara – Polatlı kesimi gerek gidiş yönünde (26,94 km) gerekse dönüş yönünde (29,62 km) IRI değerleri ağırlıklı olarak “Orta – İyi” düzgünsüzlük sınıfında çıkmıştır. Öte yandan “Çok Kötü” sınıfındaki değerler Polatlı – Ankara (Gidiş) yönünde 12,64 km ile Ankara – Polatlı (Dönüş) yönünde olan 3,92 km’den oldukça büyükür. Polatlı – Ankara (Gidiş) yönü diğer yön göre daha yetersizdir.

3.2.2. Tekerlek İzinde Oturma (TİO) Analizleri

Profilometre Ölçüm Cihazı ile ölçümler tamamlanan kesimde elde edilen TİO değerleri aşağıda belirtilen kriterler doğrultusunda sınıflandırılmıştır.

<table>
<thead>
<tr>
<th>Tekerlek İzinde Oturma Değeri (TİO - mm)</th>
<th>TİO Sınıflaması</th>
<th>Öncelik Sınıfı</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 5</td>
<td>İyi</td>
<td>4</td>
</tr>
<tr>
<td>5 - 15</td>
<td>Orta</td>
<td>3</td>
</tr>
<tr>
<td>15 -30</td>
<td>kötü</td>
<td>2</td>
</tr>
<tr>
<td>&gt; 30</td>
<td>Çok Kötü</td>
<td>1</td>
</tr>
</tbody>
</table>

3.2.3. Yüzey Bozulmaları Analizleri

Yüzey bozulma analizleri Karayolları Genel Müdürlüğü’nce belirlenen sınıflandırma kriterleri doğrultusunda Profilometre ölçüm cihazı kameraları tarafından 20 m aralıklarla çekilen yüksek çözünürlüklü yüzey görüntülerinin üst yapımı mühendisleri tarafından incelenmesi ile yapılmıştır. Bu aşama için geliştirilen özel bir yazılım sayesinde görüntüler üzerinde her bir yüzey bozulma tipi şiddetleri ile birlikte belirlenmiş ve işaretlenerek kayıt altına alınmıştır.

<table>
<thead>
<tr>
<th>Sır No</th>
<th>Yüzey Bozulma Tipli</th>
<th>Yüzey Bozulma Simgesi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tekerlek İzinde Oturma - Sağ</td>
<td>TIO-R</td>
</tr>
<tr>
<td>2</td>
<td>Tekerlek İzinde Oturma - Sol</td>
<td>TIO-L</td>
</tr>
<tr>
<td>3</td>
<td>Timsah Sırtı Çatlak</td>
<td>TSÇ</td>
</tr>
<tr>
<td>4</td>
<td>Kenar Çatılagı</td>
<td>KC</td>
</tr>
<tr>
<td>5</td>
<td>Enine Çatılagı</td>
<td>EC</td>
</tr>
<tr>
<td>6</td>
<td>Boyuna Çatılagı</td>
<td>BC</td>
</tr>
<tr>
<td>7</td>
<td>Blok Çatılagı</td>
<td>BLÇ</td>
</tr>
<tr>
<td>8</td>
<td>Ondülasyon</td>
<td>ON</td>
</tr>
<tr>
<td>9</td>
<td>Oturma</td>
<td>OTR</td>
</tr>
<tr>
<td>10</td>
<td>Ötelenme</td>
<td>OTL</td>
</tr>
<tr>
<td>11</td>
<td>Yama</td>
<td>Y</td>
</tr>
<tr>
<td>12</td>
<td>Çukur</td>
<td>ÇK</td>
</tr>
<tr>
<td>13</td>
<td>Terleme</td>
<td>TR</td>
</tr>
<tr>
<td>14</td>
<td>Soyulma</td>
<td>SY</td>
</tr>
</tbody>
</table>

Resimler üzerinde işaretlenen bozulma verileri profilometre ölçümlerini ile elde edilen mesafe ve küresel konum (GPS) verileri ile de eşleştirilerek diğer parametrelerle karşılaştırılabilir hale getirilmiştir. Yapılan tüm yüzey bozulma belirlenmeleri çalışmalarını sırasında yüzey görüntülerini ile birlikte profilometre ölçüm verileri de aynı ekranda görüntülenerek veriler ile görüntüler arasında kıyaslamalar da yapılmıştır.

Şekil 3. Ankara – Polatlı Devlet Yolu Yüzey Bozulmaları Değerlendirmeleri

**ESNEK ÜST AYPILAR İÇIN ÜST AYPI DURUMU PUANLAMA TABLOSU**

![Üst Yapı Durumu Puanlama Tablosu](image)


### 3.2.4. Düşen Ağırlıklı Deflektometre Ölçüm Analizleri

KGM bünyesinde bulunan Düşen Ağırlıklı Deflektometre (FWD) ile toplanan defleksiyon verileri FWD ve kalan ömür metodu olmak üzere iki farklı yöntem ile değerlendirilmiştir.

**FWD Hesap Metodu:**


**Kalan Ömür Hesap Metodu:**

3.2.5. Bakım – Onarım Alternatiflerinin Belirlenmesi

Yapılan analizler sonucu elde edilen verilerin karşılaştırmaları sonucunda ağı düzeyinde değerlendirilmeler yapılmış ve müdahale edilmiş gerekli kesimler, öncelik dereceleri ile birlikte saptanmıştır. Belirlenen kesimlerde hangi müdahalenin daha doğru olacağını saptanması amacıyla projeyeürnberginde değerlendirilmeler yapılmıştır.


Aşağıdaki çizelgelerde Ankara – Polatlı Yolu Bakım – Onarım Alternatifleri Belirlenmeleri

<table>
<thead>
<tr>
<th>Km</th>
<th>IRI mm</th>
<th>TİO mm</th>
<th>FWD Metodu</th>
<th>Kalan Ölümü Metodu</th>
<th>Üyelikli Puanlama</th>
<th>IRI</th>
<th>TİO</th>
<th>Alternatif 1</th>
<th>Alternatif 2</th>
<th>Alternatif 3</th>
<th>Alternatif 4</th>
<th>Alternatif 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0+000</td>
<td>1.79</td>
<td>7.69</td>
<td>0.0</td>
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<td>2.3</td>
<td>1.94</td>
<td>6.55</td>
<td>Beton Yol</td>
<td>Beton Yol</td>
<td>Beton Yol</td>
<td>Beton Yol</td>
<td>Beton Yol</td>
</tr>
<tr>
<td>1+000</td>
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<td>5.40</td>
<td>7.6</td>
<td>7.4</td>
<td>4.5</td>
<td></td>
<td></td>
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<td>Beton Yol</td>
<td>Beton Yol</td>
<td>Beton Yol</td>
<td>Beton Yol</td>
</tr>
<tr>
<td>2+000</td>
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<td>5.82</td>
<td>5.5</td>
<td>1.7</td>
<td>2.4</td>
<td></td>
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<td>Beton Yol</td>
<td>Beton Yol</td>
</tr>
<tr>
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<td>6.19</td>
<td>9.0</td>
<td>3.4</td>
<td>3.4</td>
<td></td>
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<td>Beton Yol</td>
<td>Beton Yol</td>
<td>Beton Yol</td>
<td>Beton Yol</td>
</tr>
<tr>
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<td>1.92</td>
<td>6.65</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
<td>Beton Yol</td>
<td>Beton Yol</td>
<td>Beton Yol</td>
<td>Beton Yol</td>
<td>Beton Yol</td>
</tr>
<tr>
<td>5+000</td>
<td>2.49</td>
<td>4.82</td>
<td>0.7</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
<td>Beton Yol</td>
<td>Beton Yol</td>
<td>Beton Yol</td>
<td>Beton Yol</td>
<td>Beton Yol</td>
</tr>
<tr>
<td>6+000</td>
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<td>3.64</td>
<td>6.1</td>
<td>3.2</td>
<td>2.5</td>
<td>2.09</td>
<td>5.21</td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
</tr>
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<td>2.51</td>
<td>4.21</td>
<td>5.5</td>
<td>0.1</td>
<td>0.0</td>
<td></td>
<td></td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
</tr>
<tr>
<td>8+000</td>
<td>2.46</td>
<td>4.31</td>
<td>8.9</td>
<td>4.1</td>
<td>3.0</td>
<td></td>
<td></td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
</tr>
<tr>
<td>9+000</td>
<td>2.41</td>
<td>3.81</td>
<td>8.5</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
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<tr>
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<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
<td>Beton + TMA Takviye</td>
</tr>
</tbody>
</table>

Şekil 5. Ankara – Polatlı Yolu Bakım – Onarım Alternatifleri Belirlenmeleri

3.2.6. Fayda – Maliyet Analizleri ve Değer Yönetimi

Belirlenen alternatifler arasında en uygun olmanın saptanması amacıyla her alternatifin fayda ve maliyet analizleri yapılmış, bu analizler sonucunda her alternatif için Fayda/Maliyet oranları hesaplanmıştır. Fayda/Maliyet oranı en yüksek olan alternatif ise en uygun yöntem olarak belirlenmiştir.

3.2.6.1. Maliyet Analizleri

Çizelge 4. Polatlı – Ankara (Gidiş) Yönü 1. Alternatif Metraj Hesabı

<table>
<thead>
<tr>
<th>Sıra No</th>
<th>İş Kalemi Adı</th>
<th>Birim</th>
<th>Miktar</th>
<th>Birim Fiyat (TL)</th>
<th>Tutarı (TL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ASFALT KAZMA MAKİNESİ İLE BİTÜMLÜ KARŞIM KAPLAMALARINI KAZILMASI VE 2.5KM MESA斐 İÇERİSİNDEKI DEPOYA NAKLİ (53cm)</td>
<td>m³</td>
<td>63,09</td>
<td>50,21</td>
<td>3.167,77</td>
</tr>
<tr>
<td>2</td>
<td>ASFALT KAZMA MAKİNESİ İLE BİTÜMLÜ KARŞIM KAPLAMALARINI KAZILMASI VE 2.5KM MESA斐 İÇERİSİNDEKİ DEPOYA NAKLİ (&gt;53cm)</td>
<td>m³</td>
<td>5.540,40</td>
<td>50,21</td>
<td>278.183,48</td>
</tr>
<tr>
<td>3</td>
<td>SİCAK KARŞIM KAPLAMALI YOLLARDA ASFALT YAMASI YAPILMASI İŞÇİLİĞİ (PMT Malzemeleri, Bitüm, Asfalt,Distribütör İdareden)</td>
<td>m³</td>
<td>9,14</td>
<td>72,82</td>
<td>665,45</td>
</tr>
<tr>
<td>4</td>
<td>Çatlık Dolgunu Yapılması</td>
<td>m</td>
<td>26,39</td>
<td>20,00</td>
<td>527,76</td>
</tr>
<tr>
<td>5</td>
<td>MAKİNA İLE SERME, ŞIKİSTIRMA (Nakliyeler Dahil)</td>
<td>m³</td>
<td>793,440</td>
<td>3,86</td>
<td>3.062.678,40</td>
</tr>
<tr>
<td>6</td>
<td>MICROsurfacing Köprüyü Yüze Kapatılması Yapılması (TIP-3)</td>
<td>m³</td>
<td>34.800</td>
<td>154,92</td>
<td>5.391.216,00</td>
</tr>
<tr>
<td>7</td>
<td>Binder Yapılması</td>
<td>m³</td>
<td>35.496</td>
<td>91,88</td>
<td>3.261.372,48</td>
</tr>
<tr>
<td>8</td>
<td>Binder Yapılması</td>
<td>m³</td>
<td>3.167,77</td>
<td>50,21</td>
<td>3.167,77</td>
</tr>
<tr>
<td>9</td>
<td>Binder Yapılması</td>
<td>m³</td>
<td>8.700</td>
<td>143,65</td>
<td>1.249.755,00</td>
</tr>
<tr>
<td>10</td>
<td>Asfalt Betonu Aşınma Tabakası Serilmesi - Sıkıştırılması</td>
<td>m³</td>
<td>2.799,36</td>
<td>116,92</td>
<td>327.301,17</td>
</tr>
<tr>
<td>11</td>
<td>Asfalt Betonu Aşınma Tabakası Serilmesi - Sıkıştırılması</td>
<td>m³</td>
<td>0,54</td>
<td>4,96</td>
<td>2,68</td>
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</tbody>
</table>

Çizelge 4. Polatlı – Ankara (Gidiş) Yönü 1. Alternatif Metraj Hesabı

<table>
<thead>
<tr>
<th>Sıra No</th>
<th>Pozno</th>
<th>İŞ KALEMI ADI</th>
<th>Birim</th>
<th>Miktar</th>
<th>Birim Fiyat (TL)</th>
<th>Tutarı (TL)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>40.130/ÖZEL</td>
<td>ASFALT KAZMA MAKİNESİ İLE BİTÜMLÜ KARŞIM KAPLAMALARINI KAZILMASI VE 2.5KM MESA斐 İÇERİSİNDEKİ DEPOYA NAKLİ (53cm)</td>
<td>m³</td>
<td>63,09</td>
<td>50,21</td>
<td>3.167,77</td>
</tr>
<tr>
<td>2</td>
<td>40.130/ÖZEL</td>
<td>ASFALT KAZMA MAKİNESİ İLE BİTÜMLÜ KARŞIM KAPLAMALARINI KAZILMASI VE 2.5KM MESA斐 İÇERİSİNDEKİ DEPOYA NAKLİ (&gt;53cm)</td>
<td>m³</td>
<td>5.540,40</td>
<td>50,21</td>
<td>278.183,48</td>
</tr>
<tr>
<td>3</td>
<td>B-031/ÖZEL</td>
<td>SİCAK KARŞIM KAPLAMALI YOLLARDA ASFALT YAMASI YAPILMASI İŞÇİLİĞİ (PMT Malzemeleri, Bitüm, Asfalt,Distribütör İdareden)</td>
<td>m³</td>
<td>9,14</td>
<td>72,82</td>
<td>665,45</td>
</tr>
<tr>
<td>4</td>
<td>ÖZEL</td>
<td>Çatlık Dolgunu Yapılması</td>
<td>m</td>
<td>26,39</td>
<td>20,00</td>
<td>527,76</td>
</tr>
<tr>
<td>5</td>
<td>ÖZEL</td>
<td>MAKİNA İLE SERME, ŞIKİSTIRMA (Nakliyeler Dahil)</td>
<td>m³</td>
<td>793,440</td>
<td>3,86</td>
<td>3.062.678,40</td>
</tr>
<tr>
<td>6</td>
<td>ÖZEL</td>
<td>MICROsurfacing Köprüyü Yüze Kapatılması Yapılması (TIP-3)</td>
<td>m³</td>
<td>34.800</td>
<td>154,92</td>
<td>5.391.216,00</td>
</tr>
<tr>
<td>7</td>
<td>ÖZEL</td>
<td>Binder Yapılması</td>
<td>m³</td>
<td>35.496</td>
<td>91,88</td>
<td>3.261.372,48</td>
</tr>
<tr>
<td>8</td>
<td>ÖZEL</td>
<td>Binder Yapılması</td>
<td>m³</td>
<td>3.167,77</td>
<td>50,21</td>
<td>3.167,77</td>
</tr>
<tr>
<td>9</td>
<td>ÖZEL</td>
<td>Binder Yapılması</td>
<td>m³</td>
<td>8.700</td>
<td>143,65</td>
<td>1.249.755,00</td>
</tr>
<tr>
<td>10</td>
<td>16.002/K-1/ÖZEL</td>
<td>GRANÜLOMETRİK KUM VE ÇAKILLA YAP. DEMİR SİSIZ BETON (BETON SANTR. İLE Derz, Kaşp, Demir İmalatları ve Nakliyeler Dahil)</td>
<td>m³</td>
<td>2.799,36</td>
<td>116,92</td>
<td>327.301,17</td>
</tr>
<tr>
<td>11</td>
<td>50.128/ÖZEL</td>
<td>Beton Otokorkuluk Yapılması (A Tipi)</td>
<td>m</td>
<td>4.000</td>
<td>469,00</td>
<td>1.876.000,00</td>
</tr>
</tbody>
</table>
3.2.6.2. Fayda Analizleri

Fayda/Maliyet değeri, temel olarak yatırım kararlarına ait oluşan toplumsal faydaları para birimi ile ifade eden değerin yatırım maliyetine oranı ile bulunur. Çalışmada, “fayda” kalemli olarak araç işletme maliyetleri ile sürücü ve yolcu zaman maliyetleri göz önüne alınmıştır. İncelenen kesime ait IRI değerlerine göre stylesheet maliyetler “Karayolları Planlaması Bilgileri El Kitabı” kaynağından alınmıştır.

Uygulanacak üstüstek tabakasının optimum hizmet yaşına göre yapılan değerlendirmede, IRI değeri ve satış, her tabakanın optimum yaş sonunda son servis yeteneği indeksi (Pt)’nin 2,5 alt sınırına çıkmış kabul edilmiştir. Öte yandan, hiçbir iyileştirme yapılmama durumunda, yine artışta tabakanın optimum yaş sonunda son servis yeteneği indeksine inşaat kullanılması fakat, yolun İdarece bu servis kabileyetinin altında inmesine mümkün olmuyacağı teorik yaklaşıması ile son servis yeteneği indeksine karşılık gelen IRI (3,07 m/km)’nin üstüne çıkışması mümkün değildir. IRI artışının IRI – PSI değişimini için, FHWA’nın önerdiği model kullanılmıştır.


Analiz başlangıç yılı olarak 2011 yılı seçilmiştir ve fayda değerlerine iskonto yapılarak, maliyet değerlerine faiz uygulanarak maliyetler analiz başlangıç yılına dönüştürülmüştür. Bunlardan başka, çalışmada kullanılan üstüstek iyileştirme türlerine ait ortalama ömrüler NCHRP’nin 523 nolu raporunda önerildiği şekilde kullanılmıştır.

Elde edilen Fayda ve Maliyet değerleri doğrultusunda her alternatif için Fayda/Maliyet oranları hesaplanmıştır. Ankara – Polatlı Yolu Gidiş yönü için hesaplanan Fayda/Maliyet oranları aşağıdaki çizelgede yer almaktadır.

<table>
<thead>
<tr>
<th>ALTERNATİF – 1 FAYDA / MALIYET ORANI</th>
<th>ALTERNATİF – 2 FAYDA / MALIYET ORANI</th>
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</thead>
<tbody>
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<td>YAPIM METODU</td>
<td>FAYDA</td>
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<table>
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<th>ALTERNATİF – 4 FAYDA / MALIYET ORANI</th>
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<tbody>
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<td>FAYDA</td>
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<tr>
<td>BETON YOL</td>
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</tr>
<tr>
<td>TOPLAM FAYDA / MALIYET ORANI</td>
<td>7.20</td>
</tr>
</tbody>
</table>

4. **TÜRKİYE ÜSTYAPI YÖNETİM SİSTEMİ YAZILIMI**

Türkiye şartlarına uygun üstapı yönetim metotlarının belirlenmesinden sonra üstapı yönetimini ağ düzeyinde ve proje düzeyinde yukarıda yer alan yöntemlere uygun olarak yapabilen bir üstapı yönetim sistemi yazılımı oluşturulmuştur. Bu kapsamda Karayolları intranet ağ üzerinden tüm Karayolları personelinin ulaşabileceği bu yazılıma yetkilendirilen Bölge Müdürlüğü personeli tarafından veri girişi yapılmaktadır ve bu veriler yazılım tarafından otomatik olarak analiz edilmektedir.

**Şekil 6. Türkiye Üstapı Yönetim Sistemi Veritabanı**

Türkiye Üstapı Yönetim Sistemi yazılımı Türkiye Karayolu ağ için üstapı evanter arşiv programı, üstapı mevcut durum analiz programı ve üstapı yönetim sistemi programı olarak üç farklı yazılımın görevini yerine getiren tek bir yazılım olarak tasarlanmıştır. Üstapı Yönetim Sistemi tarafından yukarıdaki bölümlerde anlatılan analizlerin ve değerlendirmelerin tamamı otomatik olarak yapılabilme ve elde edilen sonuçlar karşılaştırmalı olarak değerlendirilebilmektedir. Aşağıdaki şekte Türkiye Üstapı Yönetim Sisteminin genel işleyişi yer almaktadır.
Üstüapı yönetim sisteminde bulunan tüm veriler, analizler ve değerlendirme sonuçları Coğrafi Bilgi Sistemleri ile harita üzerinde görüntülenebilmektedir.

Şekil 7. Türkiye Üstüapı Yönetim Sistemi Genel İşleyiş Şeması

Üstüapı yönetim sisteminde bulunan tüm veriler, analizler ve değerlendirme sonuçları Coğrafi Bilgi Sistemleri ile harita üzerinde görüntülenebilmektedir.

Şekil 8. Türkiye Üstüapı Yönetim Sistemi CBS Görünümü

5. SONUÇLAR


KAYNAKLAR


Noureldin, S. Ve Diğerleri, Non-Destructive Estimation of Pavement Thickness, Structural Number and Subgrade Resilience along INDO Highways, FHWA/IN/JTRP-2004/35 Son Rapor, ABD


ABSTRACT:
In Turkey, road barriers, which are used as part of the type of transportation safety in road transport are made of steel, concrete, wood, plastic, or hybrid materials that can be produced by combination of these materials. Concrete barriers are divided into two as in-situ cast or prefabricated barriers when listed according to the production method. Concrete barriers began to be used first in 1959 in the United States. In our country, the first was built in 1988 in Istanbul, Izmir and Iskenderun.

In Turkey as well as in Europe, concrete barriers that are built and tested according to EN 1317 series of standards are required to carry the CE marking under the European Regulation. In USA, performance and suitability of concrete barriers are tested according to AASTHO-MASH standard. In Turkey, the national regulations are issued by the Ministry of Environment and Urban Development and it is stated that all building materials that are placed on the market should be produced according to a harmonized standard or a European Technical Approval should possess a CE marking, and concrete road barriers fall into this category. However, even though there is a harmonized standard for ready-mix concrete, as it can not be transported and is not considered as a final product, in-situ cast concrete does not need to possess a CE mark. This often creates confusion between member states of EU, as to whether or not in-situ cast concrete barriers need to carry a CE marking or not.

This article will discuss the European and American approach of production and testing of road barriers and will deliver the recent status of in-situ cast concrete road barriers within Europe.
1 GİRİŞ


Türkiye ve Avrupa'da prefabrik beton otokorkulukların EN 1317 serisi standartlarına uygun performansı ve Yapı Malzemeleri Yönetmeliği kapsamında CE işareti taşıması gerekmektedir. ABD'de prefabrik beton otokorkulukların performansı ve uygunluğu Amerikan Devlet Karayolu ve Taşımacılığı Yetkilileri Derneği (AASHTO) tarafından yayımlanan AASHTO MASH (Güvenlik Donanım Değerlendirme Kılavuzu) kapsamında değerlendirilmektedir. Her iki standardın da kapsamları incelendiğinde prefabrik beton otokorkuluklar da dahil olmak üzere tüm araç emniyet sistemlerini kapsadığı anlaşılmaktadır.

Ülkemizde Çevre ve Şehircilik Bakanlığı’nca yayımlanan yönetmeliğe göre harmonize standardlarla üretilen bütün yapı malzemelerinin pıyasaya arz edilmesi ve piyasada bulundurulması için CE işaretli taşıma zorunluluğu bulunmaktadır. Bu bağlamda bir fabrikada belirli bir amaç için üretilen ve taşınarak nihai kullanım yerine taşınan prefabrik beton elemanında CE işaretli taşıması zorunluluğu bulunmasına rağmen, hazır beton olarak tabir edilen ve taze halde taşınarak nihai yerinde dökümü yapılan betonun piyasaya arzı esnasında ise CE işaretli taşıması zorunlu değildir.

Bu durum yerinde döküm ve prefabrik yöntemleriyle üretilmekteden beton otokorkulukların EN 1317 standartının kapsamları içerisinde prefabrik ve yerinde dökümü gerçekleştirilenlerin her ikisi de CE işaretli taşıması zorundadır. Bu çalışmada, prefabrik ve yerinde döküm beton otokorkuluklarının belgelendirmeleri hususunda Arap ve Amerika’daki uygulamaları kapsamında değerlendirilerek tartışılacaktır.

2 “CE İŞARETİ ve 05/2011/AB YAPI MALZEMELERİ YÖNETMELİĞİ (CPR)

“CE” işareti, Avrupa Birliği’nin (AB), teknik mevzuat uygunluğu çerçevesinde ürünün, serbest dolaşımını ve Côrporité européenne (CE) işareti, bir kalite belgesidir. CE işaretli, Avrupa Ekonomik Alanı genelinde tek bir işaretin kullanılmasını sağlayacaktır. CE işaretli ürünün, Avrupa Ekonomik Alanı genelinde tekn bir işaretin kullanılmasını sağlayacaktır. CE işaretli, Avrupa Ekonomik Alanı genelinde tek bir işaretin kullanılmasını sağlayacaktır. CE işaretli, Avrupa Ekonomik Alanı genelinde tek bir işaretin kullanılmasını sağlayacaktır. CE işaretli, Avrupa Ekonomik Alanı genelinde tek bir işaretin kullanılmasını sağlayacaktır. CE işaretli, Avrupa Ekonomik Alanı genelinde tek bir işaretin kullanılmasını sağlayacaktır. CE işaretli, Avrupa Ekonomik Alanı genelinde tek bir işaretin kullanılmasını sağlayacaktır. CE işaretli, Avrupa Ekonomik Alanı genelinde tek bir işaretin kullanılmasını sağlayacaktır. CE işaretli, Avrupa Ekonomik Alanı genelinde tek bir işaretin kullanılmasını sağlayacaktır. CE işaretli, Avrupa Ekonomik Alanı genelinde tek bir işaretin kullanılmasını sağlayacaktır. CE işaretli, Avrupa Ekonomik Alanı genelinde tek bir işaretin kullanılmasını sağlayacaktır. CE işaretli, Avrupa Ekonomik Alanı genelinde tek bir işaretin kullanılması zorunlu değildir.
değerlendirilmesini, bildirim mercini, onaylanmış kuruluşlar ile ilgili düzenlemeleri, piyasa gözetimi ve denetimine dair usul ve esasları kapsamaktadır.

ÇE İşaretesi Grosesi'nin ilişkin olarak 23/2/2012 tarihli ve 28213 sayılı Resmi Gazete'de yayınlanan ÇE İşareti Yönetmeliği hükümleri yapı malzemeleri hakkında da uygulanmaktadır. İmalatçı tarafından performans beyanı düzenlenmemiş ise yapı malzemesi ÇE işaretsi konulamaz. İmalatçı ÇE işaretini ilhımlenecek veya ilhımlenecektir. Sağlam sistemlerin büyük kütle ve küçük kütle viyay malzememinin beyn edilen performansına ve aynı zamanda bu yönetmelikte ve işaretlemeye ilişkin Avrupa Birliği mevzuatı uyumlaştırılan ulusal mevzuata uygunluğunun sorumluluğunu üstlenmiş olur. ÇE işareti, hakkında uyumluluğun standart veya hazırlanmış Avrupa Teknik Değerlendirme autonomy bulunan tüm yapı malzemelerinin, ilgili uyumluluk standart veya Avrupa Teknik Değerlendirme kapsamındaki temel karakteristiklerle ilişkin ise yapı edilen performansına uygun olduğunun teyidi eden tek işaretmedir. Ulusal düzenlemelerde uyumluluk standart kapsamları içindeki yapı malzemelerinin ilgili temel karakteristiklerine ilişkin performansının uygunluğunun teyidi ve işaretlemesi için ÇE işaretini dışındaki bir referans verilmeye veya ÇE işaretinin aranmayaçığına dair herhangi bir hüküm getirilmemek üzere birçok malzemenin, kullanmanın amacı için beyn edilen performans değerleri, bu kullanım amacı için istenen ulusal gereklere karşıladığı ve mevzuata uyumlu dört tek etmediği müdahale piyasada bulunması veya kullanılması engellenememe ve yasaktanamaz.

3 BETONARME YAPI ELEMANLARI VE “CE” İŞARETİ


4 AVRUPA DA GÜVENLİK BARİYERLERİ

1990’ların başında, Avrupa Standardizasyon Komitesi (CEN), yol ekipmanları için bir teknik komisyon (CEN/TC 226) ve yol güvenlik sistemlerinin standartlaştırılması üzerinde çalışmak üzere bir çalışma grubu (WG 1) oluşturmuş ve 1998 yılında Avrupa yol güvenlik sistemlerinin ilk iki bölümü (EN 1317-1 ve 2) yayınlanmış olmuştur. Aradan geçen 15 yılı aşkın sürenin ardından bugün Avrupa da yol güvenlik sistemleri için kilavuz niteliğinde olan harmonize EN 1317 standartları halihazırda yayınlanmış olan şirat aded bölümünden oluşmaktadır ve geri kalan üç bölümü (6, 7 ve 8. Bölümleri) ise henüz yayınlanmamış ve taslak halinde bulunmaktadır (Tablo 1)


Tablo 1. EN 1317 Yol Güvenlik Sistemleri Standardları

| EN 1317-1 | Yol Güvenlik Sistemleri – Bölüm-1: Terminoloji ve deney yöntemleri için genel kriterler |
| EN 1317-2 | Yol Güvenlik Sistemleri – Bölüm-2: Taşıt parapetleri için performans sınıfları, çarpma deneyi kabul kriterleri ve deney yöntemleri |
| EN 1317-3 | Yol Güvenlik Sistemleri – Bölüm-3: Çarpmaya karşılanan performans sınıfları, çarpma deneyi kabul kriterleri ve deney yöntemleri |
| EN 1317-4 | Yol Güvenlik Sistemleri – Bölüm-4: Güvenlik barierlerinin terminalleri ve geçmiş bölgeler için performans sınıfları, çarpma deneyi kabul kriterleri ve deney yöntemleri |
| EN 1317-5 | Yol Güvenlik Sistemleri – Bölüm-5: Taşıt güvenlik sistemleri için mamul gereklilikleri ve uygunluk değerlendirmesi |

Bu bölümde genel olarak; deney kabul kriterleri, terminoloji, deney yöntemleri kabul kriterleri gibi konulara yer vermektedir.

Tablo 2. EN 1317-2’de Belirtilen Standard Çarpmalar Testleri

<table>
<thead>
<tr>
<th>Test adı</th>
<th>Çarpma hızı (km/sa)</th>
<th>Çarpma açısı (derece)</th>
<th>Çarpan kütlesi (ton)</th>
<th>Çarpan aracın tipi</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB11</td>
<td>100</td>
<td>20</td>
<td>0,9</td>
<td>Araba</td>
</tr>
<tr>
<td>TB21</td>
<td>80</td>
<td>8</td>
<td>1,3</td>
<td>Araba</td>
</tr>
<tr>
<td>TB22</td>
<td>80</td>
<td>15</td>
<td>1,3</td>
<td>Araba</td>
</tr>
<tr>
<td>TB31</td>
<td>80</td>
<td>20</td>
<td>1,5</td>
<td>Araba</td>
</tr>
<tr>
<td>TB32</td>
<td>110</td>
<td>20</td>
<td>1,5</td>
<td>Araba</td>
</tr>
<tr>
<td>TB41</td>
<td>70</td>
<td>8</td>
<td>10</td>
<td>Kamyon</td>
</tr>
<tr>
<td>TB42</td>
<td>70</td>
<td>15</td>
<td>10</td>
<td>Kamyon</td>
</tr>
<tr>
<td>TB51</td>
<td>70</td>
<td>20</td>
<td>13</td>
<td>Otobüs</td>
</tr>
<tr>
<td>TB61</td>
<td>80</td>
<td>20</td>
<td>16</td>
<td>Kamyon</td>
</tr>
<tr>
<td>TB71</td>
<td>65</td>
<td>20</td>
<td>30</td>
<td>Kamyon</td>
</tr>
<tr>
<td>TB81</td>
<td>65</td>
<td>20</td>
<td>38</td>
<td>Tır</td>
</tr>
</tbody>
</table>

Tablo 3. EN 1317-2’de Belirtilen Yolda Tutma Seviyelerine ait Gereklilikler

<table>
<thead>
<tr>
<th>Yolda Tutma Seviyesi</th>
<th>Kabul Testi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Düşük açılar</td>
<td>T1 TB21</td>
</tr>
<tr>
<td></td>
<td>T2 TB22</td>
</tr>
<tr>
<td></td>
<td>T3 TB41 ve TB21</td>
</tr>
<tr>
<td>Normal</td>
<td>N1 TB31</td>
</tr>
<tr>
<td></td>
<td>N2 TB32 ve TB11</td>
</tr>
<tr>
<td>Yüksek</td>
<td>H1 TB42 ve TB11</td>
</tr>
<tr>
<td></td>
<td>L1 TB42 ve TB32 ve TB11</td>
</tr>
<tr>
<td></td>
<td>H2 TB51 ve TB11</td>
</tr>
<tr>
<td></td>
<td>L2 TB51 ve TB32 ve TB11</td>
</tr>
<tr>
<td></td>
<td>H3 TB61 ve TB11</td>
</tr>
<tr>
<td></td>
<td>L3 TB61 ve TB32 ve TB11</td>
</tr>
<tr>
<td>Çok yüksek</td>
<td>H4a TB71 ve TB11</td>
</tr>
<tr>
<td></td>
<td>H4b TB81 ve TB11</td>
</tr>
<tr>
<td></td>
<td>L4a TB71 ve TB32 ve TB11</td>
</tr>
<tr>
<td></td>
<td>L4b TB71 ve TB32 ve TB11</td>
</tr>
</tbody>
</table>

Çarpma testlerinden beklenen bir başka husus da çarpışma esnasında sürücünün can güvenliğidir. Bunun için geliştirilen iki indeksden biri çarpma şiddetini ölçmeye yarayan ASI değeri, diğeri ise sürücünün başında darbe esnasında oluşan şiddetini ölçen THIV değeridir. Bu değerler sadece araba kullanılarak yapılan çarpma testlerinde hesaplanır ve bu değerler ile Tablo 4’te gösterilen çarpma şiddet seviyesi bulunur.
SON İÇERİK

Son olarak çarpma testlerini sırasında güvenlik barierlerinin deformasyonu, çalışma genişliği, dinamik yer değişirme ve taşıt ihlal mesafesi olmak üzere üç parametre ile ölçülmektedir. Yüksek hızlı kamera yardımcı ile belirlenen bu parametreler test sonrası yapılan ölçümler kullanılarak standartlaştırılmaktadır. Test esnasında araçın davranışını da belirlenmektedir, ancak bir tekerden daha fazlasına birer aşması istenmemektedir. Öte yandan Avrupa standartlarında barierlerin kurulumunun yapılacağı zeminin tasarımında belirtildiği gibi olması gereklidir.

Standard herhangi bir şekilde barierin imal edileceği malzeme tanımlamak, aşağıdaki bilgilerin teknik tarifinin yapılması talep edilmektedir:

- Sistemin, kurulum planı montaj tarifleri ve toleransları ile birlikte genel yerleşim çizimleri,
- Bileşenlerin, boyutlar ve toleransları ile birlikte geometrik çizimleri ile tüm malzeme özellikleri,
- Tüm malzelerin ve tüm son yüzey kaplamaların (uygulanan koruyucu sistem dâhil) özellikleri,
- Mamulün dayanıklılık değerlendirilmesi,
- Fabrikada kısmi montajı yapılmış bileşenlerin çizimleri,
- Kurtarıcı de dâhil olmak üzere tüm parçaların listesi,
- Ongörüme işlemine ilişkin ayrıntılar (ilgili durumlarda),
- Varsa ilgili diğer bilgiler (geri çevrim bilgisi, çevre, emniyet gibi),
- Mevzuat gerekli olan bilgiler.


ABD’DE GÜVENLİK BARIYERLERİ


Tablo 4. EN 1317-2’de Belirtilen Çarpma Şiddeti Seviyeleri

<table>
<thead>
<tr>
<th>Çarpma Şiddeti Seviyesi</th>
<th>İndeks Değerleri</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>ASI ≤ 1.0</td>
</tr>
<tr>
<td>B</td>
<td>1.0 &lt; ASI ≤ 1.4</td>
</tr>
<tr>
<td>C</td>
<td>1.4 &lt; ASI ≤ 1.9</td>
</tr>
<tr>
<td></td>
<td>THIV ≤ 33 km/sa</td>
</tr>
</tbody>
</table>

Tablo 5. ABD’de Güvenlik Barierleri

**Tablo 5. AASHTO-MASH Tarafından Kapsanan Yol Güvenlik Sistemleri**

<table>
<thead>
<tr>
<th>Yol güvenlik özellikleri</th>
<th>Açıklama</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bariyerler</td>
<td>Esnek ve yarı esnek bariyerler</td>
</tr>
<tr>
<td></td>
<td>Rijit bariyerler</td>
</tr>
<tr>
<td></td>
<td>Bariyer arası geçiş bölgeler</td>
</tr>
<tr>
<td>Terminaller</td>
<td>Çelik otokorkuluklar</td>
</tr>
<tr>
<td></td>
<td>Refüj bariyerleri</td>
</tr>
<tr>
<td>Çarpma yastıkları</td>
<td>Yönlendiren</td>
</tr>
<tr>
<td></td>
<td>Yönlendirmeyen</td>
</tr>
<tr>
<td>Destek yapıları</td>
<td>Kırılabilen aydınlatma lambaları ve işaretler</td>
</tr>
<tr>
<td></td>
<td>Elektrik kablo sou taşınan direktler</td>
</tr>
<tr>
<td></td>
<td>Çalışma bölgesi trafik kontrol cihazları</td>
</tr>
<tr>
<td>Çalışma bölgesi hız kesiciler ve yönendirciler</td>
<td>Kamyonete bağlı hız kesiciler</td>
</tr>
<tr>
<td></td>
<td>Yönlendirciler</td>
</tr>
<tr>
<td></td>
<td>Diğerleri</td>
</tr>
<tr>
<td>Diğer cihazlar</td>
<td>Trafik ştleri</td>
</tr>
<tr>
<td>Drenaj ve diğer geometrik özellikler</td>
<td></td>
</tr>
</tbody>
</table>

**Tablo 6. AASHTO-MASH’de Belirtilen Standard Çarpma Testleri**

<table>
<thead>
<tr>
<th>Test seviyesi</th>
<th>Çarpma hızı (km/sa)</th>
<th>Çarpma açısı (derece)</th>
<th>Çarpan kütle (ton)</th>
<th>Çarpan aracın özellikleri ve tipi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>25</td>
<td>1,100</td>
<td>1100C (Araba)</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>25</td>
<td>2,270</td>
<td>2270P (Kamyonet)</td>
</tr>
<tr>
<td>2</td>
<td>70</td>
<td>25</td>
<td>1,100</td>
<td>1100C (Araba)</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>25</td>
<td>2,270</td>
<td>2270P (Kamyonet)</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>25</td>
<td>1,100</td>
<td>1100C (Araba)</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>25</td>
<td>2,270</td>
<td>2270P (Kamyonet)</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>25</td>
<td>1,100</td>
<td>1100C (Araba)</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>25</td>
<td>2,270</td>
<td>2270P (Kamyonet)</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>15</td>
<td>10,000</td>
<td>10000S (Kamyon)</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>25</td>
<td>1,100</td>
<td>1100C (Araba)</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>25</td>
<td>2,270</td>
<td>2270P (Kamyonet)</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>15</td>
<td>36,000</td>
<td>36000S (Tır)</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>25</td>
<td>1,100</td>
<td>1100C (Araba)</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>25</td>
<td>2,270</td>
<td>2270P (Kamyonet)</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>15</td>
<td>36,000</td>
<td>36000S (Tır)</td>
</tr>
</tbody>
</table>

ABD’de yollarda yüksek hacimli ve yüksek hızda arabaaralara yaşayan trafik kazalarının incelemesi sonucunda kazaların %85’inin 100 km/sa ve 25 derecelik açılarla gerçekleştiği ortaya konulmuştur. Benzer şekilde düşük hacimli yollarda ise 70 km/sa ve 50 km/sa’lık hızların daha büyük oranda gerçekleştiği anlaşılaktan bariyerlerin testlerinde bu hızlar kullanılmıştır. Ayrıca, ağır taşların karşıt noktası kazalarda ise hız sınırsı 80 km/sa, çarpma açısı ise 15 derece olarak belirlenmiştir. Bu değerler gözönüne alınarak bariyerlerin çarpma testlerinin hangi kombinasyonlardan oluşması gerektiğini belirlemiştir (Tablo 7). Ayrıca, çarpma testlerinin bariyerlerin en kritik yerlerinde yapılması gerektiğini belirtmiş ve bunlar Resim 1’de gösterilmiştir.

![Resim 1](https://example.com/resim1.png)

(a) 10, 11 ve 12 no’lu testler
(b) 20, 21 ve 22 no’lu testler

**Resim 1. AASHTO-MASH’te Belirlenen Kritik Çarpma Bölgenleri**

Avrupa standartlarından farklı olarak oldukça detaylı bir şekilde testlerin yapılacak yerin tarifi yapılmış, zeminin testler üzerindeki etkisi üzerinde durularak özellikle çelik bariyerlere ait sütunların zeminine ankraj edilmesi
durumunda zemin özelliklerinin iklimle değişebileceğini göz önünde alınarak dinamik çarpmalardan önce statik deneylerle birlikte yapılabilmesi ve dinamik deney sayısının bu şekilde azaltılabileceğini belirtmiştir.

<table>
<thead>
<tr>
<th>Test no</th>
<th>Test seviyesi</th>
<th>Bariyer</th>
<th>Araç tipi</th>
<th>Çarpma hızı (km/sa)</th>
<th>Çarpma açısı (dergree)</th>
<th>Minimum Çarpma enerjisi (kJ)</th>
<th>Değerlendirme Kriteri</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kendisi</td>
<td>1-10</td>
<td>1-11</td>
<td>50</td>
<td>25</td>
<td>17,4</td>
<td>A,D,F,H,I</td>
</tr>
<tr>
<td></td>
<td>Geçiş Bölgesi</td>
<td>1-20</td>
<td>1-21</td>
<td>50</td>
<td>25</td>
<td>17,4</td>
<td>A,D,F,H,I</td>
</tr>
<tr>
<td>2</td>
<td>Kendisi</td>
<td>2-10</td>
<td>2-11</td>
<td>70</td>
<td>25</td>
<td>34,2</td>
<td>A,D,F,H,I</td>
</tr>
<tr>
<td></td>
<td>Geçiş Bölgesi</td>
<td>2-20</td>
<td>2-21</td>
<td>70</td>
<td>25</td>
<td>34,2</td>
<td>A,D,F,H,I</td>
</tr>
<tr>
<td>3</td>
<td>Kendisi</td>
<td>3-10</td>
<td>3-11</td>
<td>100</td>
<td>25</td>
<td>69,7</td>
<td>A,D,F,H,I</td>
</tr>
<tr>
<td></td>
<td>Geçiş Bölgesi</td>
<td>3-20</td>
<td>3-21</td>
<td>100</td>
<td>25</td>
<td>69,7</td>
<td>A,D,F,H,I</td>
</tr>
<tr>
<td>4</td>
<td>Kendisi</td>
<td>4-10</td>
<td>4-11</td>
<td>100</td>
<td>25</td>
<td>69,7</td>
<td>A,D,F,H,I</td>
</tr>
<tr>
<td></td>
<td>Geçiş Bölgesi</td>
<td>4-20</td>
<td>4-21</td>
<td>100</td>
<td>25</td>
<td>69,7</td>
<td>A,D,F,H,I</td>
</tr>
<tr>
<td>5</td>
<td>Kendisi</td>
<td>5-10</td>
<td>5-11</td>
<td>100</td>
<td>25</td>
<td>69,7</td>
<td>A,D,F,H,I</td>
</tr>
<tr>
<td></td>
<td>Geçiş Bölgesi</td>
<td>5-20</td>
<td>5-21</td>
<td>100</td>
<td>25</td>
<td>69,7</td>
<td>A,D,F,H,I</td>
</tr>
<tr>
<td>6</td>
<td>Kendisi</td>
<td>6-10</td>
<td>6-11</td>
<td>100</td>
<td>25</td>
<td>69,7</td>
<td>A,D,F,H,I</td>
</tr>
<tr>
<td></td>
<td>Geçiş Bölgesi</td>
<td>6-20</td>
<td>6-21</td>
<td>100</td>
<td>25</td>
<td>69,7</td>
<td>A,D,F,H,I</td>
</tr>
</tbody>
</table>

ABD standartlarına göre herhangi bir yol güvenlik sisteminin değerlendirilmesinde i) Yapısal yeterlilik, ii) sürücü güvenliği ve iii) aracın yönlendirilmesi olmak üzere üç ana faktör kullanılmaktadır ve A'dan N'ye kadar isimlendirilen toplam 11 kriter kullanılmaktadır. Sadece bariyerlere ilişkin olarak belirlenen değerlendirme kriterleri Tablo 8'de özetlenmiştir. Tablodan da görüleceği üzere tpkti Avrupa standartlarına benzer şekilde kısıtlamalar bulunmaktadır ancak aracın yönlendirilmesi bulunmamaktadır.

<table>
<thead>
<tr>
<th>Değerlendirme Faktörü</th>
<th>Değerlendirme Kriteri</th>
<th>Uygulanacak Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yapısal Yeterlilik</td>
<td>A: Bariyer belirli sınırlar içerisinde esneyebilmeli ancak test aracını bariyerin altında, üstünden geçmemeli, bariyer içerisinde kalmalıdır.</td>
<td>10, 11, 12, 20, 21, 22</td>
</tr>
<tr>
<td>Sürücü Güvenliği</td>
<td>D: Bariyerden kopan parçalar gerek sürücüye gerekse yoldan geçen diğer yayalara ve araçlara zarar vermemelidir. Test aracına verilen hasar belirli sınırlar içerisinde kalmalıdır.</td>
<td>10, 11, 12, 20, 21, 22</td>
</tr>
<tr>
<td></td>
<td>G: Her ne kadar zorunlu olmasa da çarpma sonrasında test aracının tekerleklerinin üzerinde durmalı ters ya da yan dönmemesi aranmaktadır.</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>H: Darbe kaynaklı yolcu hızı mümkün 9.1 m/s’den az olmalı, 12.2 m/s’yi kestirilecek aşmamalıdır.</td>
<td>10, 11, 20, 21</td>
</tr>
<tr>
<td></td>
<td>I: Yolcu durma ivmesi mümkün 15G’den az olmalı, 20G’yi aşmamalıdır.</td>
<td>10, 11</td>
</tr>
</tbody>
</table>

Tablo 8. AASHTO-MASH’de Bariyerler için Belirtilen Değerlendirme Kriterleri
SONUÇ

Avrupa Birliği üyeleri tarafından kabul edilen EN 1317 ve ABD tarafından kullanılan AASHTO-MASH standardlarının otoyol bariyerlerinden beklenildiği her ikisinde de benzer şekilde gerçek anlama dinamik çarpma deneyleri yapıldığı, bu amaçla farklı tip ve büyüklüklerde araçların kullanıldığı görülmekteidir. Yine benzer şekilde her ikisinde de bariyerden bariyerin deformasyonu, araçtaki sürücüde oluşması muhtemel hasar ve araçın çarpma sonrası davranışdır. Her ne kadar bu benzerlikler bulunsa da her iki standard arasında detaylarda farklılıklar bulunmaktadır. ABD’de ve Avrupa’da da kullanılan bu farklılıklar standardlara da yansıtılmış ve ABD’de daha büyük araba ve kamyonlar çarpma testlerinde kullanılabilmektedir. Ancak bu kütle, hız ve çarpma açıları düşünüldüğünde uygulanan test matrisleri arasındaki kinetik enerjiler arasında benzerlikler bulunmaktadır. Sürücü üzerinde yapılan ölçümlerde de önemli farklılıklar bulunmaktadır.

Her iki standarda göre de bariyerlerde kullanılan malzemeye yönelik bir açıklama yer almamakta ancak kullanım yerine göre bariyer seçimi yol tasarım mühendislerine bırakılmaktadır. Örneğin, İngiltere’de refüjlerde deformasyon yapmayan böylece karşı tarafların çarpma geçişine izin vermeyen beton bariyerlerin kullanımı zorunlu tutulmuştur. Belçika gibi birçok Avrupa ülkesinde ise yine refüjlere de benzer şekilde özellikle otoyolların eğimlerindeki geçişlerinde yerinde dökme beton bariyerler tercih edilmektedir. ABD’de de benzer şekilde özellikle otoyolların eğimlerindeki geçişlerinde yerinde dökme beton bariyerler tercih edilmektedir.

7 KAYNAKLAR

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ANAHTAR KELİMELER
Darbe, dikme, modelleme, otokorkuluk, sonlu elemanlar, zemin.

ÖZET
Otokorkuluk, çarpma yastığı, üç terminalleri ve benzeri yol kenar koruyucu yapıları, yol platformuna paralel olarak refüje veya yol kenarında inşa edilen, araçların yoldan çıkmaları durumunda çarpma ihtimali bulunan sonu artisansız engellerdir. Otokorkuluklar, yol kenar koruyucu yapıları içerisinde en yaygın olarak kullanılanıdır; canlı-cansız varlıkların güvenliğini korumak amacıyla tasarlanır. Otokorkuluklar, karayollarında kullanılan pasif güvenlik tertibatlarından biridir ve araç darbesi olana kadar yol güvenliğine katkıda bulunmazlar. En hafifinden en ağırına kadar her türlü araç darbeine göre performans sınıfları bulunan otokorkuluklar, genel olarak çelik ve beton malzeme kullanılarak imal edilirler. Ulkemizde çelik otokorkuluk kullanımı beton otokorkulüğa göre daha yaygın. Otokorkuluklar genel olarak düşey doğrultudaki dikme, yatay doğrultudaki ray ve dikmeye yaya bağlı bir takozun birleştirilmesiyle oluşturulur. Bu çalışmada, zeminlerde çakılı otokorkuluk dikkatlerinin darbe yükleri altında davranışını incelemiştir. Çalışmanın amacı, karayollarımızda kullanılmaktadır standart otokorkuluk dikkatlerinin optimum gömülme derinliklerinin zemin özelliklerine bağlı olarak belirlenmesidir. Farklı zemin ve dikme tipleri,

Deneysel çalışmadan elde edilmiş sonuçlar kullanılarak zemin özelliklerine göre yeterli otokorkuluk çakılma derinlikleri belirlenmektedir. Bu sayede gerekiz malzeme kullanımını azaltılacak, otokorkulukların çakımında kullanılan iş ve makine gücünden tasarruf sağlanacaktır. Dolaysıyla binlerce kilometre otokorkuluk çakımı yapılan ülkemizde, çalışmanın sonuçları ekonomik açıdan önemlidir.
Zemine Çakılı Otokorkulukların Darbe Davranışının Sonlu Elemanlar Analiziyle İncelenmesi

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1. GİRİŞ


En hafifinden en ağırına kadar her türlü araç darbelerine göre performans sınıfları bulunan otokorkuluklar, genel olarak çelik ve beton malzemeden imal edilirler. Ülkemizde çelik otokorkuluk kullanımı daha popülerdir. Otokorkuluklar genel olarak düşey doğrultudaki dikme, yatay doğrultudaki ray ve dikmeyi raya bağlayan bir takozun birleştirilmesiyle oluşturulur. Dikmeler C veya sigma kesitine sahipken, ray 2 veya 3 boğumlu. Dikme ile ray arasında kullanılan takoz farklı geometriye sahip olabilir. Şekil 1'de ülkemizde karayollarında kullanılan sigma ve C kesitli dikmeleri ait örnek resimler bulunmaktadır.

Şekil 1. Karayollarında kullandığı dikme geometrileri (a) sigma dikme ve (b) C dikme

Çelik otokorkulukları inşa yöntemlerine göre iki grupta toplanmak mümkündür: (1) zemine çakılanlar ve (2) betona ankarjlananlar. Beton üzerine ankarjlanan otokorkuluklar sadece köprü, viyadük ve benzeri özel durumlarda kullanılacağı için kullanım oranları çakılan sistemlere oranla daha düşüktür. Şekil 2’de zemine çakılan ve betona ankarjlanan otokorkulu tiplerine ait örnek resimler ve zemine çakılan spesifik bir otokorkuluğa ait ölçüleri gösterilmektedir. Şekil 3’te, zemine çakılan otokorkuluk dikmelerinin beliri bir bölümü zemin üzerinde kalırken beliri bir bölümü de zemin içerisinde kalmaktadır. Zemin seviyesi altındaki dikme kısımlar sistemin zemine mesnetlenmesini sağlamakta ve otokorkuluğa araç darbesi esnasında sistemin darbe yüklerine karşı direnç oluşturmasını yardımcı olmaktadır. Bu sebeple otokorkulukların zemine çakılamaları derinlikleri, otokorkuluk performansına etki eden oldukça önemli bir parametredir. T.C. Karayolları tarafından standart olarak kabul edilen otokorkuluk sistemlerinde kullanılan dikmelerin uzunluk bilgileri Tablo 1’de verilmiştir. Tabloda dikkate alınmayan detay, otokorkulukların çakıldığını zeminin özellikleridir. Zemin
türü ne olursa olsun aynı otokorkuluk derinliği kullanılmaktadır. Şekiller 4-5’te bir çarpışma testi sonrasında görevini yaparak deforme olmuş otokorkuluk dikme resimleri vardır. Dikmeler, çarpan aracın enerjisini yutmada katkıda bulunan ve zeminde kalan iç kısımdan burkularak deforme olmuştur. Bu durumlarda dikken çekilen bir konu dikkatini çeken zemin özelliklerinin test sonucuna etkisi olmasına rağmen standartlarda zemin özellikleri ve dikme-zemin etkileşimi ile ilgili hiçbir tanımlama yapılmamış olmasdır. Zemin özelliklerine göre dikme derinliği tanımlanmadığından dolayı otokorkuluk üreticileri çarpışma testlerinde standart kullanılan otokorkuluk gömülme derinliklerini kullanarak risk almama yoluna gitmektedir. Otokorkuluk dikkmerinin boyundaki ve dolaysıyla ağırlığındaki küçük bir azalma da bu çakılan binlerce kilometrelük otokorkuluk için inanılmaz bir tasarruf sağlayabilir.

Şekil 2. Çelik otokorkuluklar (a) zemine çakılan (b) betona ankralı tasarımlar

Şekil 3. Zemine çakılan örnek bir otokorkuluğa ait mesafeler

Şekil 4. 10 tonluk kamyon ile yapılan otokorkuluk çarpışma testi öncesi aracın otokorkuluğa çarpma ve çarpışma testi sonucunda başarıyla tamamlanmış test ve sistem deformasyonu

Şekil 5. (a) Aynı çarpışma testi sonucunda enerji yutarak deforme olmuş dikmeler ve çarpan bölgesindeki dikme-zemin etkileşiminin (b) Çarpışma testi sonrasında plastik deformasyon yapan C kesiti dikkemler


Tablo 1. Ülkemizde standart olarak kullanılan bazı otokorkulu dikmelerine ait uzunluk ve oranlar

<table>
<thead>
<tr>
<th>Otokorkuluk Sınıfı</th>
<th>Dikme Kesiti</th>
<th>Dikme Toplam Boyu (mm)</th>
<th>Zemine Gömülme Derinliği (mm)</th>
<th>Zemin Üzerindeki Kısımın Uzunluğu (mm)</th>
<th>Dikme Gömülme Derinliği/Zemin Üstündeki Uzunluk</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 ton kamyon kadar olan araçları tutmak için tasarlanmış sistemler</td>
<td>C 120</td>
<td>1600</td>
<td>950</td>
<td>650</td>
<td>1.462</td>
</tr>
<tr>
<td></td>
<td>Sigma 100</td>
<td>1900</td>
<td>1200</td>
<td>700</td>
<td>1.714</td>
</tr>
<tr>
<td>10 tondan daha ağır vasıtaları tutmak için tasarlanmış sistemler</td>
<td>C 150</td>
<td>2400</td>
<td>1230</td>
<td>1170</td>
<td>1.051</td>
</tr>
</tbody>
</table>

2. MATERIAL VE YÖNTEM


Şekil 6. Taşıyıcı dış çerçeve ve 750 kg ağırlığındaki kütlenin SolidWorks programı kullanılarak hazırlanmış 3 boyutlu modeli (sol) yan görüntü, (sağ) isometrik görüntü

Zemin ve dikme modellerinin geometrileri SolidWorks programı kullanılarak 3 boyutlu olarak hazırlanmıştır. Standart dikme geometrileri kullanılarak istenen uzunlukta modellenen dikmeler silindir şeklinde zemin tabakasının içerisine yerleştirilmiştir. Şekil 7'de örneğin bir durum için oluşturulan dikme-zemin modeli görülmektedir. Dikme gömülme derinlikleri her durum için kolayca değiştirilerek kaydedilebilmektedir.

Şekil 7. Dikme ve zemin modellerinin SolidWorks programı kullanılarak hazırlanmış 3 boyutlu görüntü

Arazide yapılan sarkaç deneylerine uygun olarak SolidWorks’ta hazırlanan 3 boyutlu model IGES (.igs) formatında kaydedilerek ikinci aşama modelleme olan sonlu elemanlar çalışması başlatılmıştır. Model LS-PrePost isimli programında açılan sarkaç elemanlarına sonlu eleman ağ (mesh) atılmıştır. Oluşturulan eleman ağında eleman büyüklükleri 25 mm x 25 mm lik kare olarak seçilmiştir. Bu boyutun seçilmesi ile hesaplar doğru olarak ilerlemiş ve sarkaç elemanları arasındaki etkileşim hassas şekilde yapılabilmiştir. Sarkacın sonlu elemanlar ağı oluşturulmuş görüntüüsü Şekil 8’dedir. Sarkacın sonlu elemanlar ağının tamamlanmasından sonra malzeme parametrelerinin atanması ve şekil özellikleri verilmiştir.

Şekil 8. Sarkacın LS-PrePost kullanılarak mesh oluşturulmuş görüntüüsü (sol) yan görüntü, (sağ) isometrik görüntü

Şekil 9. Zemin tabakaları ve C dikmenin LS-PrePost kullanılarak oluşturulmuş görüntüsü


Şekil 10. D-C600 durumu için sayisal analize hazır model

Şekil 11. Sayısal analizde kullanılan sonlu elemanlar ağının yakından görüntüümü
3. ANALİZ SONUÇLARI VE KARŞILAŞTIRMA


Şekil 12. D-C600 testi görsel sonuçlarının karşılaştırılması

![D-C600 testi görsel sonuçlarının karşılaştırılması](image)

Şekil 13. D-C600 ara testi ve sayısal analizinden elde edilen ivme-zaman grafiklerinin karşılaştırılması

![D-C600 testi ve sayısal analiz grafikleri](image)
Şekil 14. D-C900 testi görsel sonuçlarının karşılaştırılması

Şekil 15. D-C900 arazi testi ve sayısal analizinden elde edilen ivme-zaman grafiğinin karşılaştırılması

TEŞEKKÜR
Bu bildiri Tübitak Mühendislik Araştırma Grubunun 213M516 nolu projesi kapsamında yapılmıştır. Araştırmacılardan desteklerinden dolayı Tübitak'a teşekkür bir borç bilmiyorsunuz.

KAYNAKLAR
Yük Taşımacılığında Yönlendirici Algoritmaların Oluşturulması

Özet

Anahtar Kelimeler; Yük Taşımacılığı, Filo Yönetimi, Akıllı Ulaşım Sistemleri, Yük optimizasyonu
İçindekiler
1. Giriş ................................................................................................................................................. 5
2. Lojistik Yönetim Sistemleri Kavramsal Çerçevesi ............................................................... 6
  2.1. Lojistik Altyapı Sistemleri ........................................................................................................ 7
  2.1.1. Karayolu Taşımacılığı ........................................................................................................... 8
  2.1.2. Demiryolu Taşımacılığı ....................................................................................................... 10
  2.1.3. Denizyolu Taşımacılığı ....................................................................................................... 11
  2.1.4. Havayolu Taşımacılığı ........................................................................................................ 14
  2.2. Lojistik Bölgeleme ve Yer Seçimi ........................................................................................... 14
  2.2.1. Lojistik Köy/Merkez Kavramı ............................................................................................. 14
  2.2.2. Lojistik Köy/Merkez Planlama Sistemi .............................................................................. 15
  2.2.3. Lojistik Köy/Merkez Yer Seçimi .......................................................................................... 16
  2.2.4. Dünya ve Türkiye’den Lojistik Köy/Merkez Örnekleri .................................................. 16
    2.2.4.1 Lojistik Köyler ve TCDD Lojistik Merkezleri ............................................................... 18
    2.2.4.2 Karayolu Lojistik Merkezleri ......................................................................................... 20
    2.2.4.3 Eşya/Kargo Terminal İşletmeleri ................................................................................... 20
  2.3. Lojistik Erişilebilirlik ve Kısıtlamalar ...................................................................................... 21
    2.3.1 Taşıma tür seçimi ................................................................................................................ 21
    2.3.2 Taşıma Türüne Kolay Erişim ............................................................................................. 22
    2.3.3 Taşıma Süresi ..................................................................................................................... 23
    2.3.4 Bedel ve Tarifeler ................................................................................................................. 23
    2.3.5 Güvenlik ............................................................................................................................. 24
    2.3.6 Yasal Mevzuat ve Düzenlemeler ....................................................................................... 24
  2.4. Lojistik Trafik Yönetimi .............................................................................................................. 27
  2.5. Lojistik Bilişim Teknolojileri .................................................................................................... 29
2.6. Operasyonel Lojistik Yönetimi

2.6.1 Tedarik Zinciri Lojistik Yönetimi (Supply Chain Logistics Management)

2.6.2 Tam Zamanında Üretim/Teslimat (Just In Time Manufacturing and Delivery)

2.6.3 Çapraz Sevkiyat (Cross Dock)

2.6.4 Yüklemeye Optimizasyonu (Loading Optimisation)

2.6.5 Çağdaş Depo Tasarımı ve Yönetimi

2.6.6 Sürekli Gelişim ve İnovasyon

2.7. Afet Lojistiği

2.8. Kentsel lojistik en iyi uygulama örnekleri

2.8.1 Londra

2.8.2 Lyon

2.8.3 Burgos (İspanya)

2.8.3.1 CIVITAS-CARAVEL Projesi
ŞEKİL LİSTESİ
Şekil.1 Lojistik Yönetim Birimleri ........................................................................................................ 7
Şekil.2 İstanbul’da Lojistik Odak ve Terminaller ................................................................................. 8
Şekil.3 Lojistik Merkez Organizasyon Yapıısı (Bentzen vd, 2003) ....................................................... 17
Şekil.4 TCDD Lojistik Merkezleri ......................................................................................................... 19
Şekil.5 Akıllı Ulaşım Sistemleri ......................................................................................................... 27
Şekil.6 Trafik Kontrol Merkezi ............................................................................................................ 29
Şekil.8 Lojistik Bilgi Sistemleri’nin haritası (Kaynak: warehows.org) ................................................. 30
Şekil.9 Londra’da Stratejik yük güzergahları (Transport for London, 2010) ........................................... 32
Şekil.10 Lyon’da İdari Sınırlar (Grand Lyon) ...................................................................................... 35
Şekil.11 Lyon yük noktaları (Only Lyon, 2011) ..................................................................................... 36

TABLO LİSTESİ
Tablo.1 Yıllar İtibariyle İşletmeye Açık Otoyollar(km) ...................................................................... 9
Tablo.2 Türkiye ve İstanbul geneli motorlu kara taşıtları sayısı (2015 Mayıs, TÜİK) ............... 9
Tablo.3 Liman Tesisleri Bazında Elde Edilen Yükün Dağılımı – 2011(Ton) .............................................. 12
Tablo.4 En Fazla Konteyner Elde Edilen 10 Liman Başkanlığı (TEU) ..................................................... 13
Tablo.5 Lojistik Ulusal ve Uluslararası Mevzuatlar ........................................................................... 26
1. GİRİŞ


Lojistik faaliyetlerin verimliliği gelişmiş bir ulaştırma sisteminin oluşturulmasıyla doğru orantılıdır. Gelişmiş bir ulaştırma sistemi, mal ve ürünlerin hem çeşitliliğinin artmasına hem de ihtiyaç duyan yerlerde yeteri miktarda bulunmasına olanak sağlar. İşlevsel açıdan ele alındığında ulaştırma sistemleri temel olarak aşağıdaki temel bileşenlerden oluşmaktadır:

- Tesisler ve altyapı: karayolları (devlet yolları), çevreyolları (ödemeli/ücretli yollar), demiryolları ve istasyonlar, havalimanları, (deniz/suyolu) limanları ve su kanalları, boru hatları.

- Araçlar ve araç filoları: karayolu araçları, lokomotifler, gemiler ve diğer suyolu araçları, uçaklar.

- İşletmeler ve organizasyonlar: demiryolları, havayolları, gemi işletmecileri, kara taşımacılığı ve karma taşımacılık yapan nakliye şirketleri; havalimani işletmecileri, liman işletmeleri, karma taşımacılık istasyonları işletmecileri; altyapıdan sorumlu devlet organizasyonları, yerel yönetimlerin ulaştırma altyapısını ve planlaması ile ilgili birimler, yerel ulaştırma daireleri.

- İşlevsel tesisler ve ilgili işletmeler: bakım-onarım merkezleri (demiryolu, havayolu ve suyolu araçları) ve işletmecileri, inşaat şirketleri gibi altyapı kurucuları ve müteahhit firmaları, hava kontrol merkezleri, deniz trafik kontrol organizasyonları

- Operasyon stratejileri ve yasalar: havayolu, karayolu, denizyolu trafik kontrolü, ulusal kalkınma planları ve stratejik planlar, ulusal ve yerel yasalar, uluslararası kuruluşlar ve anlaştırmalar, uluslararası kurallar ve kanunlar, gece ve kahredici.

2. LOJİSTİK YÖNETİM SİSTEMLERİ KAVRAMSAL ÇERÇEVESİ


Kent trafığı kentsel lojistik faaliyetlerin zaman ve parasal maliyetlerini arttırmaktadır. Piyasada rekabet koşullarının korunması temel ilke alınarak işletmelerin hizmet düzeyini düşürmeden kentsel lojistik maliyetlerinin azaltılması için küçük, orta ve büyük ölçekli her tür
perakende işletmelerinin dağılımı ve yoğunlaşma bölgeleri, ulaştırma altyapısı ve tüketici nüfusun dağılımı dikkate alınarak dağıtım merkezlerinin (konsolidasyon-dekonsolidasyon işlemleri dahil) planlanması, taşın hareket güzergah ve çalışma saatlerinin düzenlenmesi gerekmektedir. Şekil.’de lojistik yönetim merkezinde kurulması gereken lojistik yönetim birimleri gösterilmektedir.

Şekil.1 Lojistik Yönetim Birimleri

2.1. Lojistik Altyapı Sistemleri

Türkiye nüfusunun yanı sıra ticari ve endüstriyel faaliyetlerin de önemli bir kısmının İstanbul ve yakın çevresinde toplandığı ve şehir içi mal dağıtımı ile birlikte şehirlerarası ve uluslararası taşımacılık faaliyetlerini de kapsayan lojistik sektörünü İstanbul’dan çok önemli bir konuma taşıtmıştır. Yapılan rekabet analizleri ve diğer çalışmalarda lojistik sektörü İstanbul’un bölgesel merkez olma potansiyeline katkıda bulunacak temel alanlardan birisi olarak belirlemiştir. Bununla birlikte lojistik odaklar şehir içerisinde plansiz ve dağıtık olarak gelişmiştir. Yetersiz demiryolu ve liman altyapısı nedeniyle, Türkiye genelinde olduğu gibi İstanbul’da da lojistik faaliyetler büyük oranda karayolu altyapısı kullanmaktadır. Bu durum karayolu altyapısı üzerinde büyük baskılar yaratarak bir yandan lojistik sektörünün verimlilik ve rekabet düzeyini düşürmekte, diğer taraftan yolcu ulaşımını büyük oranda...
etkilemektedir. İstanbul’un Boğaz tarafından ikiye bölünmüş yapısı nedeniyle, gerek İstanbul üzerinden yapılan transit taşımıcılık, gerekse iki yaka arasındaki karayolu taşımacılığı büyük oranda mevcut köprülerden sadece birini sınırlı saatlerde kullanılmaktadır. 

Şekil.2’dede İstanbul’da Lojistik Odak ve Terminaller gösterilmektedir. 

![Şekil.2 İstanbul’da Lojistik Odak ve Terminaller](image)

**Lojistik Odaklar:** Organize Sanayi Bölgeleri (OSB), Küçük Sanayi Siteleri (KSS), Münferit Fabrikalar, İmalathaneler, Depolar, Antrepolar, Tersaneler, Maden Bölgeleri, Tarım/Hayvancılık Çiftliği, Toptan/Perakende Satış Yeri, Atık Toplama Merkezi, Diğer Lojistik Odaklar

**Terminaller:** Havaalanları Kargo Terminalleri (Atatürk Havaalanı Kargo Terminali, Sabiha Gökçen Havaalanı Kargo Terminali), Deniz Limanları ve Tersaneler (Ambarlı Limanı, Haydarpasa Limanı, Pendik RO-RO Limanı ve Diğerleri), Demiryolu Yük Merkezleri (Halkalı Gümrük Alani, RO-LA terminali vb.), Karayolu Yük Terminalleri (Ambarlar, Haller, Kargo İşleme Teslileri vb.), Gümrük, Diğer Lojistik Terminaller

**2.1.1. Karayolu Taşımacilığı**

Ülkemizde yük taşınmacılığının %89’una yakın bir bölümü karayollarımız üzerinde gerçekleşmektedir. Ekonomik kalkınmanın ve refahın gelişmesinde büyük rolü olan karayolu taşımacılığı, kendi bünyesi içinde başlı başına bir ekonomik faaliyet olduğu gibi diğer bütün
sektörlere de çok yakın ilişkisi olan ve bu sektörleri olumlu veya olumsuz yönde etkileyen bir hizmet sektörüdür.

Karayolları Genel Müdürlüğü verilerine göre yıllarda göre işletmeye Açık Otoyollar(km) Tablo.1’de gösterilmektedir.

Tablo.1 Yıllar İtibariyle İşletmeye Açık Otoyollar(km)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>İstanbul</td>
<td>1.674</td>
<td>1.696</td>
<td>1.714</td>
<td>1.753</td>
<td>1.662</td>
<td>1.667</td>
<td>1.908</td>
<td>1.908</td>
<td>1.922</td>
<td>2.036</td>
<td>2.080</td>
<td>2.119</td>
<td>2.127</td>
<td>2.127</td>
<td>2.155</td>
</tr>
<tr>
<td>Toplam</td>
<td>1.674</td>
<td>1.696</td>
<td>1.714</td>
<td>1.753</td>
<td>1.662</td>
<td>1.667</td>
<td>1.908</td>
<td>1.908</td>
<td>1.922</td>
<td>2.036</td>
<td>2.080</td>
<td>2.119</td>
<td>2.127</td>
<td>2.127</td>
<td>2.155</td>
</tr>
</tbody>
</table>

Tablo.2 Türkiye ve İstanbul genelinde motorlu kara taşıtları sayısı (2015 Mayıs, TÜİK)

<table>
<thead>
<tr>
<th>İl</th>
<th>Toplam</th>
<th>Otomobil</th>
<th>Minibüs</th>
<th>Otobüs</th>
<th>Kamyonet</th>
<th>Kamyon (1)</th>
<th>Motosiklet</th>
<th>Özel amaçlı</th>
<th>Traktör</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toplam-Total</td>
<td>19 328 083</td>
<td>10 171 414</td>
<td>435 838</td>
<td>213 739</td>
<td>3 149 759</td>
<td>790 369</td>
<td>2 871 591</td>
<td>42 269</td>
<td>1 653 104</td>
</tr>
<tr>
<td>İstanbul</td>
<td>3 482 803</td>
<td>2 352 304</td>
<td>76 683</td>
<td>45 856</td>
<td>601 854</td>
<td>130 123</td>
<td>248 748</td>
<td>5 497</td>
<td>21 738</td>
</tr>
</tbody>
</table>

(1) Ağır tonajlı yük taşıtlarını da kapsar (çekici, damperli kamyon, tanker, çöp kamyonu vb.).

2015 yılı itibariyle Türkiye ve İstanbul genelinde motorlu kara taşıtları sayısı (trafiğe kayıtlı araç sayısı) Tablo.2’de gösterilmektedir. Türkiye’deki motorlu kara taşıtları sayısının %18’ini İstanbul oluşturuyor. Mayıs ayı sonu itibariyle trafige kayıtlı toplam 3 milyon 482 bin 803 adet taşıtın %67,5’ini otomobil, %17,2’sini kamyonet, %7,1’ini motosiklet, %3,7’sini kamyon, %2,2’sini minibüsler oluşturuyor.


İstanbul’un şehirici lojistik faaliyetlerinde olduğu kadar diğer şehir ve bölgelere yükün taşımında karayolları önemli bir paya sahiptir. İki yaka arasındaki geçişlerde lojistik faaliyetlerde kullanılan ağır vasıtalar sadece günün belli saatlerinde Fatih Sultan Mehmet
Köprüsünü (FSM) kullanabilmektedir. FSM Köprüsü ayrıca İstanbul üzerinden gerçekleştirilen yurtdışı ve uluslararası karayolu transit trafiğini de üstlenmektedir.


2.1.2. Demiryolu Taşımacılığı


Demiryolu sektöründe gerek İstanbul gerekse Türkiye ölçeğinde önemli gelişmelerden biri Marmaray Boğaz Geçişi‘dir. Boğaz geçiyle birlikte Halkalı-Gebze arasında toplam uzunluğu 77 km olan Marmaray’dan, mevcut banliyö güzergahındaki iki olan hat sayısının üçe çıkarması ve hatların 100 km/saat proje hızına ulaşacak şekilde geometrik standardın iyileştirilmesi hedeflenmektedir. İki hat banliyö trenleri, üçüncü hat ise şehirlerarası yük ve yolcu trenleri için kullanılacaktır. Sadece İstanbul’un iki yakasını değil, Avrupa ve Asya gibi iki büyük kıtayı da birbirine bağlayacak dünyada en önemli demiryolu projelerinden olan Marmaray’ın devreye girmesiyle Çin’den Avrupa’ya demiryolu ulaşımdında önemli koridorlardan biri haline gelecektir. Marmaray hattında yük trenlerinin yanı sıra kamyonların

Demiryolu Yük İstasyonları - Halkalı ve Haydarpaşa İstasyonları, uluslararası ve şehirler arası yük taşımacılığına hizmet vermektedir. Mevcut taşıma kapasitemizin en iyi şekilde kullanılarak daha hızlı ve etkin bir taşımacılık yapılaması amacıyla 2004 yılı başından itibaren yük taşımacılığında Blok Tren İşletmeciliğine geçilmiştir. Blok Tren İşletmeciliğine geçmesiyle, taşınan yük miktarında artış sağlanmış, kaynaklar daha etkin kullanılmış, taşıma süreleri kısaltılarak, müşteri memnuniyetini de artırılmıştır.

**2.1.3. Denizyolu Taşımacılığı**

Limanlar itibariyle; İstanbul Bölge Müdürlüğü’nde 14 adet Liman Başkanlığı, 58 adet iskele Türkiye’de 70 adet Liman Başkanlığı, 137 adet iskele mevcuttur.

İstanbul Liman Başkanlığı ; Liman Başkanlıkları sınırları içerisinde bulunan 500 GRT ve üzeri gemilerin yanaşabileceğini Kamu/Özel liman ve iskeleler aşağıdaki listelenmektedir.

1) Mobil Oil Türk A.Ş. – Serviburnu Tesisi
2) TCDD – Haydarpaşa Limanı
3) Salıpazarı Limanı /TDİ A.Ş. İstanbul Liman İşletmesi Müdürlüğü
4) Zeyport Zeytinburnu Liman İşletmeleri San. ve Tic. A.Ş.
5) Petrol Ofisi A.Ş. Çubuklu Depo Müdürlüğü
6) Petrol Ofisi A.Ş. Haramidere Tesisat Müdürlüğü

Yük elleçleme miktarlarını Liman Tesisleri bazında dağılımı Tablo.3’de gösterilmektedir.
<table>
<thead>
<tr>
<th>Liman Başkanlığı</th>
<th>Liman Tesisleri Bazında Elleçlenen Yükün Dağılımı – 2011(Ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>İşahat</td>
</tr>
<tr>
<td>Ahirkapsı Demirleme Mevki</td>
<td>118</td>
</tr>
<tr>
<td>Haydarpaşa TCDD Limanı</td>
<td>682.340</td>
</tr>
<tr>
<td>İstanbul Mobil Oil Servisburo Terminali</td>
<td>0</td>
</tr>
<tr>
<td>İstanbul Selin K.Tankeri Depolama Tesisii</td>
<td>0</td>
</tr>
<tr>
<td>İstanbul Zeyport Limanı</td>
<td>28.837</td>
</tr>
<tr>
<td>Kartal Kumcular Iskeleleri</td>
<td>0</td>
</tr>
<tr>
<td>Yenikapı İDO Terminali</td>
<td>0</td>
</tr>
<tr>
<td>Yeşilköy THY Opet Terminali</td>
<td>0</td>
</tr>
<tr>
<td>Toplam</td>
<td>711.295</td>
</tr>
</tbody>
</table>

Kaynak: T.C. Ulaştırma Denizcilik ve Haberleşme Bakanlığı Deniz Ticareti Genel Müdürlüğü, 2012

Liman başlıklarına göre en fazla konteyner elleçlenen liman başkanlıkları arasında Ambarlı 1.sırada yer almaktadır.
Tablo 4: En Fazla Konteyner Elleçlenen 10 Liman Başkanlığı (TEU)

<table>
<thead>
<tr>
<th>Liman Başkanlığı</th>
<th>Toplam Elleçleme (TEU)</th>
<th>Toplam Elleçleme İçindeki (%) Oran</th>
<th>Önceki Yıla Yükselen (%)</th>
<th>Liman Başkanlığı</th>
<th>Toplam Elleçleme (TEU)</th>
<th>Toplam Elleçleme İçindeki (%) Oran</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 AMBARLI</td>
<td>2.624.711</td>
<td>40,23</td>
<td>6,53</td>
<td>AMBARLI</td>
<td>2.463.866</td>
<td>42,9</td>
</tr>
<tr>
<td>2 MERSİN</td>
<td>1.126.866</td>
<td>17,27</td>
<td>10,96</td>
<td>MERSİN</td>
<td>1.015.567</td>
<td>17,68</td>
</tr>
<tr>
<td>3 GEMLİK</td>
<td>757.128</td>
<td>11,61</td>
<td>33,83</td>
<td>GEMLİK</td>
<td>716.083</td>
<td>12,47</td>
</tr>
<tr>
<td>4 İZMİR</td>
<td>672.486</td>
<td>10,31</td>
<td>-6,09</td>
<td>İZMİR</td>
<td>565.756</td>
<td>9,85</td>
</tr>
<tr>
<td>5 İZMİT</td>
<td>507.837</td>
<td>7,78</td>
<td>22,09</td>
<td>İZMİT</td>
<td>415.944</td>
<td>7,24</td>
</tr>
<tr>
<td>6 ALİAĞA</td>
<td>377.147</td>
<td>5,78</td>
<td>64,21</td>
<td>ALİAĞA</td>
<td>229.672</td>
<td>4</td>
</tr>
<tr>
<td>7 İSTANBUL</td>
<td>206.082</td>
<td>3,16</td>
<td>64,57</td>
<td>İSTANBUL</td>
<td>125.222</td>
<td>2,18</td>
</tr>
<tr>
<td>8 ANTALYA</td>
<td>165.474</td>
<td>2,54</td>
<td>-5,92</td>
<td>ANTALYA</td>
<td>175.888</td>
<td>3,06</td>
</tr>
<tr>
<td>9 TRABZON</td>
<td>40.251</td>
<td>0,62</td>
<td>18,14</td>
<td>TRABZON</td>
<td>34.072</td>
<td>0,59</td>
</tr>
<tr>
<td>10 İSKENDERUN</td>
<td>25.564</td>
<td>0,39</td>
<td>3445,63</td>
<td>İSKENDERUN</td>
<td>721</td>
<td>0,01</td>
</tr>
<tr>
<td>DIĞER LIMANLAR</td>
<td>19.959</td>
<td>0,31</td>
<td></td>
<td></td>
<td>665</td>
<td>0,01</td>
</tr>
<tr>
<td>TOPLAM ELLEÇLEME</td>
<td>6.523.506</td>
<td>100</td>
<td>13,58</td>
<td></td>
<td>5.743.455</td>
<td>100</td>
</tr>
</tbody>
</table>

Kaynak: T.C. Ulaştırma Denizcilik ve Haberleşme Bakanlığı Deniz Ticareti Genel Müdürlüğü, 2012

Ambarlı liman alanı genişlemeye uygun olmayan bir konumda bulunmaktadır. Limana ilişkin bir diğer önemli sorun limanın mevcut demiryolu ağına entegre edilmemiş olması nedeniyle hinterland ile bağlantısının karayolu ile sağlanmasıdır. Bu bağlamda, liman bölgesinin genişleyen kentin yerleşim bölgeleri arasında kalması nedeniyle mevcut karayolu bağlantılarında yaşanan yoğunluk hem limana erişimi hem de kent içi ulaşımı etkilemektedir. Haydarpaşa liman alanının yerleşimin ve nüfus yoğunluğunun yüksek olduğu kent merkezinde kalması ve genişlemesine imkân tanıyacak bir konumda bulunması nedeniyle, limanın uzun vadede tasfiye edilerek liman alanının dönüşümü planlanmaktadır. Bu nedenlerle yeni yatırımların yapılmadığı ve geleceğine ilişkin belirsizliklerin sürdüğü...
Haydarpaşa Limanı’nda taşınan yük miktarında son yıllarda önemli oranda azalmalar yaşanmıştır.

2.1.4. Havayolu Taşımacılığı

Havayolu yük taşımacılığı, denizyolu yük taşımacılığında olduğu gibi, daha çok uluslararası ticarette önemli rol oynamaktadır. Tüm dünyada ülkeler arası artan etkileşimin bir sonucu olarak hava taşımacılığı gelişmekte ve sektörre olan talep hızla artmaktadır. Ticaret ortaya çıkan büyüme, teknolojinin gelişmesi ile geniş gövdeli uçakların üretimi, yeni hizmet sunum süreçleri gibi etkenler, sektörün ilerleyen yıllarda öneminin daha da artacağını göstermektedir.

Atatürk Havalimanı’ndaki bagaj, kargo ve posta dahil toplam yük trafiği 2002-2012 arasında yılda ortalama %10 büyüme kaydetmiştir. Bu dönemde toplam yük trafiği 480.022 tondan 1.231.504 tona ulaşmıştır. 2002-2012 arasında iç hatlardaki yük trafiği yıllık ortalama %9 artarak 79.400 tondan 185.105 tona, dış hatlardaki yük trafiği ise yıllık ortalama %10 artarak 400.622 tondan 1.046.398 tona ulaşmıştır.

Atatürk Havalimanı’nın 2012 yılı yük trafiğinin dağılımına bakıldığında ise kargo ve bagaj trafiğinin ağırlığı görülmektedir. Toplam kargo, posta ve bagaj trafiğinin hepsinde dış hatlar büyük ağırlığa sahip olup özellikle kargo trafiğinde diğerlerine göre bu ağırlık çok daha fazladır.


2.2. Lojistik Bölgeleme ve Yer Seçimi

2.2.1. Lojistik Köy/Merkez Kavramı

Lojistik merkezler (logistics center); kentsel lojistik sorunlarına bütünsel (holistic) bir yaklaşım getiren çözümlerdir. Tanım olarak Lojistik Merkez; lojistik ve taşınmacılık şirketleri (dağıtım şirketleri, taşınmacılık şirketleri, lojistik hizmet sağlayıcılar-3PL) ve konu ile ilgili resmi kurumların içinde yer aldığı, her türlü ulaştırma ağına etkin bağlantıları olan ve yükleri...
farklı taşımacılık modları arasında düşük maliyetli, hızlı ve güvenli aktarma donanımlarına sahip organize lojistik bölgelerdir. Lojistik Merkezler/Köyler, Dağıtım Merkezleri, Limanlar, Demiryolu Platformları, Katı Atık Toplama ve İmha Tesisleri gibi lojistik merkezler kategorisindedir.

Lojistik Merkezlerde;

- Kent dışından ve içinden gelen yükler depolanabilmekte
- Elleçleme, konsolidasyon, de-konsolidasyon gibi operasyonlar gerçekleşirilebilmekte
- Gümrükleme, gözetim, kalite kontrol işlemleri, katma değerli işlemler yapılabilmekte
- Intermodal taşımacılık için gerekli ekipmanları barındırmakta
- Serbest bölge için yer ayrılabilmekte
- Uzun mesafeli taşıma gerçekleştirebilirme
- Konteyner ve araç park alanları bulunmaktadır
- Sosyal tesisler bulunmaktadır.

2.2.2. Lojistik Köy/Merkez Planlama Sistemiştiği


- Altyapı rasyonalizasyonu yoluyla bölgesel planlamının gerçekleştirilmesi,
- Taşımacılık kalitesinin artırılması,
- İntermodal taşımacığın gelişirilmesi,

şeklinde ifade edilmektedir.
Bir bölgenin, ulaşım, lojistik ve dağıtım hizmetlerine yönelik olarak planlanması o bölgenin optimum kullanımını, çevresel faktörlerin (trafik, hava kirliliği) minimize edilmesini sağlar. Bu nedenden dolayı, lojistik hizmet sağlayıcılarının ihtiyaçları dikkate alınarak belirlenmiş asgari kriterlere uygun altyapıların oluşturulması ve altyapının rasyonalizasyonu da önem teşkil etmektedir.

2.2.3. Lojistik Köy/Merkez Yer Seçimi

Tüm lojistik ve taşımacılık şirketler için lojistik merkezin konumu çok önemli bir etmendir. Lojistik merkezlerin görevleri arasında taşıma bağlantıları arasındaki akışı sağlamak ve tüm lojistik faaliyetleri koordine etmek yer alır. Bu yüzden Avrupa’da lojistik merkezlerin büyük çoğunluğu üretim veya tüketim merkezlerine yakın, taşımacılık ve dağıtım faaliyetlerinin merkezinde, mümkün olduğunca ulaşım modlarının tümünü kullanabileceği (hava, kara, demir, deniz) alt yapıya sahip kilit noktalarda yer almaktadır.

2.2.4. Dünya ve Türkiye’den Lojistik Köy/Merkez Örnekleri

Dünya ticaretindeki dönüşümlerle birlikte ülkelerin lojistik faaliyetlere bakış açısı hızla değişmektedir. Her ülke denizyolu, havayolu, demiryolu, karayolu ve boru hattı taşımacılık anlayışlarını uluslararası ticaret bir parçası olarak yeniden ele almakta, kendisi için en yüksek katma değeri sağlayacak yatırımlara yönelmektedirler. Bu yönelme, tüm taşıma türlerinin birbirine entegre olduğu uluslararası ölçekte faaliyet gösteren lojistik merkezler olarak karşılık bulmaktadır.

Bu bölümde dünyanın değişik bölgelerinde, gerek liman şehirlerinde gerekse iç bölgelerde konuşlanmış bazı lojistik merkezler incelenmektedir. Avrupa’da lojistik merkezlerinin genel karakteristiği incelediğine, lojistik merkezler için ortak özellikler veya temel unsurlar şu özelliklere sahiptir;

1. Lojistik merkezlerin optimal operasyonu sağlayabilecekleri ve gelişimi için en az 50-150 ha kadar alana sahip olmalıdır,

2. Kent merkezlojistik problemlerinin çözümünde etkin rol alan lojistik merkezler, büyük şehirlerin dışında, yerleşim bölgelerinden uzak ama şehre yakın yerlerde konuşlanmalıdır,

3. Ulaştırma alt yapısına erişim öncelikli olup, lojistik merkezler uluslararası ve ulusal ulaştırma güzergâhlarının üzerinde veya yakın yerlerde konuşlanmalıdır,

4. Liman şehirlerinde lojistik merkezin ticari faaliyetlerinin önemli bir bölümü denizyolu yüklerinden oluşmakta olup, kentsel lojistik sorunlar yaratmadığı sürece merkezler liman sahasına olabildiğince yakın yerlerde konuşlanmalıdır.

5. Büyük şehirlerde, son müşteriye yakın yerlerde konuşlanmış birkaç lojistik merkez ve/veya dağıtım alternatifleri ağı söz konusu olabilir. Bu durumda, lojistik merkezin bir kesişim noktasına yakın bir yerde konuşlandırılması kabul edilmektedir. Bu

**Şekil 3 Lojistik Merkez Organizasyon Yapı (Bentzen vd, 2003)**
lokasyon, genellikle büyük kentsel öğelerin kesişim noktası olmaktadır. Bir başka önemli alan da, lojistik merkezin hizmet sunduğu arz toplama bölgesidir.

2.2.4.1 Lojistik Köyler ve TCDD Lojistik Merkezleri


MADDE 8.ı) Lojistik köy, merkez veya üslerin yer, kapasite ve benzeri niteliklerini belirleyerek planlamak, kurulmalara ilişkin usul ve esasları belirlemek ve izin vermek, gerekli arazi tahsisi ile altyapıların kurulması hususunda ilgili kuruluşları koordine etmek ve uygulamasını takip etmek ve denetlemek.

Bu karanameden önce Türkiye Cumhuriyeti Devlet Demiryolları (TCDD) kent merkezi içinde kalmış olan yük garlarını; Avrupa ülkelerinde olduğu gibi, etkin karayolu ve deniz ulaşımı bağlantısı olan ve yükleyiciler tarafından tercih edilebilir bir alanda, yük lojistik ihtiyaçlarına cevap verebilecek özelliğe, modern, teknolojik ve ekonomik gelişmelere uygun şekilde, öncelikle Organize Sanayi Bölgelerine yakın ve yük potansiyeli yüksek olan İstanbul (Halkali/Yeşilbayır), İzmit (Köseköy), Samsun (Gelemen), Eskişehir (Hasanbey), Kayseri (Boğazköy), Balıkesir (Gökköy), Mersin (Yenice), Uşak, Erzurum (Palandöken), Konya (Kayaçık), Denizli (Kalklık) ve Bilecik (Bozüyük) olmak üzere 12 adet lojistik merkez kurulmaya başlanmıştır, Kahramanmaraş (Türkoglu), Mardin, Kars, Sivas, Bitlis (Tatvan) ve Habur Lojistik Merkezleri ile birlikte Lojistik Merkez adeti 19’a ulaşmıştır (TCDD, 2014).
Şekil 4 TCDD Lojistik Merkezleri

Samsun (Gelemen), Uşak, Denizli (Kaklık), İzmit (Köseköy), Eskişehir (Hasanbey) ve Halkalı olmak üzere 6 adet Lojistik Merkez işletmeye açılmıştır. Balıkesir (Gökköy), Bilecik (Bozüyük), Mardin, Erzurum (Palandöken) ve Mersin (Yenice) lojistik merkezlerinin inşaat çalışmaları devam etmektedir. Diğer Lojistik merkezlerine ilişkin proje, kamulaştırma ve inşaat ihale işlemleri sürülmektedir.

Bu lojistik merkezlerde aşağıdaki tesisler bulunacaktır:

• Konteyner yükleme, boşaltma, transfer ve stok alanları,
• Gümrüklü gümrüksüz sahalar/depolar,
• Müşteri ofisleri, otopark, TIR parkı,
• Bankalar, restoranlar, oteller, bakım onarım ve yıkama tesisleri, akaryakıt istasyonları, antrepolar,
• Tren teşkil kabul ve sevk yolları,

TCDD Lojistik merkezleri daha ziyade kendisinin hizmet verdiği demiryolu ile gelen ve giden yüklerin konsolidasyonu ve dekonsolidasyonuna yönelik aktarma terminali kapsamındadır. “Lojistik Merkez” tanımı mevzuatta TCDD’nin görev ve sorumluluk alanları kapsamında tanımlanmaktadır.
2.2.4.2 Karayolu Lojistik Merkezleri

Özel sektör taşımacılık şirketlerinin bir araya gelerek oluşturdukları kente ve ana karayolu ulaşım güzergahına yakın yerlere konuşlandırılan karayolu taşımacılığına yönelik konsolidasyon ve dekonsolidasyon merkezleridir. Depolama ve taşımacılık hizmetleri verirler. Böylece kent içinde dağıtık bir şekilde hizmet veren taşımacılık ve depolama şirketleri ortak bir mekân kullanmanın sinerjisinden yararlanırlar. En tipik örneği Ankara Kazan Lojistik Üssüdür. 45 uluslararası taşımacılık şirketi tarafından kooperatif statüsünde kurulan sonra anonim şirkete dönümüş yaklaşık 700.000 m² brut alana sahip olup, 198.000 m² si kapalı, diğer kısmı açık alandır. 400’den fazla şirket ve yaklaşık 2.000 kişi çalışmaktadır, günde 2.500 TIR-Kamyon trafiği bulunmaktadır. İçinde depo/antrepolar, bürolar, gümrük idaresi, bakım-onarım ve akaryakıt tesisi, TIR-Kamyon parkı ve sosyal tesisler bulunmaktadır. Otoyol bağlantısı olan lojistik üssünün demiryolu bağlantısı yoktur.


2.2.4.3 Eşya/Kargo Terminal İşletmeleri

Bu tür işletmeler Karayolu Taşıma Yönetmeliğinde; “Bu Yönetimelike belirtilen özellikleri haiz ve yurtiçi ve uluslararası eşya/kargo taşımacıları/işletmecileri ve/veya acenteleri, komisyoncuları, taşıma işleri organizatörleri ile bunların eşya/kargo gönderenlerine/gönderilenlerine hizmet veren yapı veya tesi” olarak tanımlanmakta ve T3 yetki belgesi ile faaliyet göstermektedirler. Eğer bu tesislerde yükleme/boşaltma/aktarma vb. işlemler yapılyorsa ve acente/komisyoncu/organizatörler faaliyet gösteriyorsa T3 belgesi alınması gerekmektedir. Sadece garaj/park hizmeti verenlerin belge ihtiyacı
bulunmamaktadır. Ülkemizde çok sayıda olmasa da Gebze’deki Marmara Nakliyciler Terminali bu tür bir merkezdir.

2.3. **Lojistik Erişilebilirlik ve Kısıtlamalar**

İstanbul’un ulaşım sisteminin, sürdürülebilirlik ilkesi doğrultusunda, kentsel yaşam kalitesini artıran, toplumun tüm kesimleri için yüksek düzeyde erişilebilirlik sağlayan bir sistem olarak geliştirilmesi şehrin önceliklerinden birini teşkil etmektedir. Uzun vadede sürdürülebilir bir ulaşım sisteminin oluşturulması için ise raylı sistemlerin ağırlıklı olduğu toplu taşımacılığın yaygınlaştırılması, deniz taşımacılığının etkinleştirilmesi, kent içi ve uluslararası yük ve yolcu taşımacılığının kent içi ulaşma etkisini azaltacak şekilde, karayolu, demiryolu, denizyolu ve havayolu gibi farklı ulaşım türlerinin etkin bir şekilde entegrasyonunun yanı sıra, mevcut karayolu altyapısının rasyonel bir şekilde kullanmasına yönelik çözümlere ihtiyaç duyulmaktadır.

Taşımacılıkta lojistik anlayışın gelişmesi, çeşitli taşımacılık alt sistemlerinden en verimli şekilde yararlanılması olanağını vermektedir. Bir taşımacılık sistemi, farklı özelliklere sahip karayolu, demiryolu, denizyolu, havayolu, içsu yolu ve boru hattı gibi çeşitli taşımacılık sistemlerinden oluşur ve her biri ayrı avantaj ve dezavantajlara sahiptir. Her bir taşımacılık alt sisteminin ekonomik koşullarda yaşadığı yük tipleri, taşıma maliyetleri, taşıma şekilleri, taşıma mesafesi ve çevresel özellikleri farklıdır.

**2.3.1 Taşıma türü seçimi**

Yükün (karakteristik) özellikleri, taşıma türüne kolay erişim, bedel ve tarifeler, taşıma süresi, yüklerin güvenliği, ve yasal mevzuatla ilgili hükümler göz önüne alınarak yapılmalıdır.

Yükün Özellikleri ; Yüklerin doğasından gelen karakteristik özellikleri, taşıma türüyle uyumunu belirlemekte önemlilikle göz önune alınması gereken unsurlardır. Yükün çeşitli özellikleri bazı taşma türlerinin seçilmesini en baştan engelleyebileceğini gibi bazı taşıma türlerinin de ön plana çıkmaması neden olabilir. Yükün özellikleri üzerinde dururken ele almamız gereken özellikleri aşağıdaki şekilde sıralandırabiliriz:

- **Boyutu:** Yükün ölçüleri ve hacimleri.
- **Ağırlık ve Yoğunluğu:** Yükün mutlak ağırlığı ve hacmiyle birlikte hesaplanması gereken yoğunluğu.
- **(Maddi) Değer:** Yükün maddi ve ticari değeri.
İstiflenebilirliği: Genellikle, boyutu ve yoğunluğu tarafından belirlenebilecek bir özellik olarak düşünülmelidir. Çok büyük ve ağır bir yükü istiflemek orta büyüklükteki birkaç parçadan oluşan bir yükü istiflemeye göre çok daha zordur. Birçok küçük ve haif parçalardan oluşan bir yük istiflenmeye çok elverişlidir, ancak bu tip yükler de çok fazla elleçleme gerektirir.


Yük özelliklerini öncelikli olarak göz önüne almak, gönderici ve alıcı tarafların hedefleri doğrultusunda seçilebilecek taşıma türünü belirlemeye önemli bir rol oynayacaktır. Ancak diğer unsurların da göz ardı edilmemesi gerekir. Daha sonra bahsedeceğimiz gibi uluslararası lojistikte karma taşımacılıkın yerli ve öncesi büyük. Zira mesafelerin daha uzun olması ve coğrafı şartlardaki değişiklikler farklı taşıma türlerinin kullanılmasını zorunlu kılarken yüklerin farklı taşıma türleriyle uyum sağlanması için özel önlemler alınması gereklidir.

2.3.2 Taşıma Türüne Kolay Erişim

Göndericiler ve alıcılar her türlü taşıma türüne kolaylıkla erişemeyebilirler. Örneğin, tomruk taşımacılığı ve maden taşımacılığı için ekonomik açıdan en uygun seçim su kanalları ya da su

2.3.3 Taşıma Süresi


2.3.4 Bedel ve Tarifeler

Ulaştırma maliyetleri taşıma türine bağlıdır ve genellikle taşıma türünün hızı ile orantılı bir şekilde artış gösterir. Diğer bir deyişle, taşıma süresinin uzun olduğu sistemlerde maliyetlerin düşük olması taşıma bedellerinin de daha düşük olması sağlarken, taşıma süreleri kısaltıkça maliyetlerin artış ı da bedellerin artmasına neden olmaktadır. Ulaştırma maliyetlerinin karakteristik özellikleri ve bunların bedel vetarifelerin belirlenmesinde nasıl bir rol oynadığı daha sonra Ulaştırma Ekonomisi bölümünde kısaça ele alınacaktır. Taşıma türü
seçiminde taşıma bedelleri ve tarifeler, göndericinin amaçladığı müşteri memnuniyeti ve hizmet seviyesine bağlı olarak önemli bir rol oynayacaktır. Ancak bu aynı zamanda yüklerin değerinin de ön plana çıkarılması gereken bir unsur olarak ele alınmalıdır. Örneğin, diğer taşımatiplerine göre daha pahalı olan havayolu taşımacılığında yüksek değerli yükler taşıırken demiryolu taşımacılığı bedellerin daha uygun olması nedeniyle değeri daha düşük yüklerin taşımasını tercih edilir.

2.3.5 Güvenlik


2.3.6 Yasal Mevzuat ve Düzenlemeler

Uluslararası taşımacılıkta gümrük işlemleriyle ilgili düzenlemeler, kaçakçılığı engellemeyi amaçlayan düzenlemeler ve ülkeler arası hukuca bağlı yasal çerçeve mekanizmaları da taşıma türünün seçiminde göz önüne alınması gereken unsurlardır. Ekonomik düzenlemelerin bir kısmı ise taşıma tipleri arasındaki seçimleri etkileyecek ve dolayısıyla ekonomik aktivitenin yönünü belirleyecek şekilde yapılacaktır. Örneğin, karayolu taşımacılığında geçerli olan yük boyutu ve ağırlığı ile ilgili olan birçok kısıtlama yalnızca yüklerin güvenli bir şekilde taşınmasıyla ilgili değil aynı zamanda karayolu taşımacılığının çok tercih edilen bir taşıma türü olmaktan çıkarmaya yönelik hedefleri de içermektedir.

Büyükşehir Belediyeleri Ulaşım Koordinasyon Merkezleri; Karayolu taşımacılığına ait mevzuat hükümleri saklı kalmak üzere, trafik düzeni ve güvenliği yönünden belediye sınırları içinde ticari amaçla çalıştırılacak yolcu ve yük taşıtları ile motorsuz taşıtların çalışma şekilleri ve şartları ile bu taşıtların teknik özelliklerini tespit etmek, çalıştırılabileceği yerler ile güzergâhlarını tespit etmek ve sayılarını belirlemek, bunlara izin ve çalışma ruhsatı vermekle görevli ve yetkilidir.

Toplu Ulaşım Hizmetleri Müdürlüğü'nde; Kara, deniz ve raylı toplu ulaşım araçlarından; Minibüs, Taksi, Taksi Dolmuşlara, Deniz Araçlarına, Servis Araçlarına, Ağır Tonajlı Araçlara; Ruhsat ve Güzergah izin belgesi vermek, Zaman ve ücret tarifelerinin belirleyerek UKOME'ye rapor halinde sunmak, Mevzuat, kurallara riayet, yolcularla ilişkiler ve taşımacılık ilkeleri yönünden denetim yapmak, bu araçların sürücü ve kullanıcılarına yönelik eğitim hizmetlerini yürütmek yönündeki görevleri yapmaktadır.


Bu Yönetmeliğin amacı, karayolu taşımacı faaliyetlerini ülke ekonomisinin gerektirdiği şekilde düzenlemek; taşımacılık faaliyetlerinde düzeni ve güvenliği sağlamak; taşımacı, acente, taşıma işleri komisyonculuğu, taşıma işleri organizatörlüğü, nakliyat ambarı işletmeciliği, kargo işletmeciliği, lojistik işletmeciliği, terminal işletmeciliği, dağıtım işletmeciliği ve benzeri faaliyetleri için mali yeterlilik, mesleki yeterlilik, mesleki saygınlık ilkelerine uygun olarak pazara giriş şartları ile bu faaliyetlerde bulunanların, gönderenlerin, yolcuların, çalışanların haklarını, sorumluluklarını, yükümlülüklerini tespit etmek; taşımacılık faaliyetlerinde istihdam edilenler ile taşımacılık faaliyetlerinde yararlanan diğer taşıma sistemleriyle birlikte ve birbirlerini tamamlayıcı olarak hizmet vermesini, denetimini ve mevcut imkânların daha yararlı bir şekilde kullanılmasını sağlamaktır.

Tablo. 5 Lojistik Ulusal ve Uluslararası Mevzuatlar

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Kaynak: http://lothed.com/mevzuat
2.4. Lojistik Trafik Yönetimi

Lojistik Trafik Yönetim Sistemi, bir filonun yük optimizasyonu ve planlamasından başlayan bir kalite programı ile yükün müşteriye teslimine kadar izlenmesi, yönetilmesi ve diğer tüm yardımcı süreçlerin sırasını, birbirleri ile ilişkisini, ölçülerini ve tüm süreçlerin iyileştirilmesini amaçlayan bir yönetim sistemidir.

![Şekil 5 Akıllı Ulaşım Sistemleri](image)

Akıllı lojistik sistemlerinin yaygınlaştırılmasıyla;
1. Mevcut ulaştırma ağlarının en uygun ve verimli şekilde kullanılması,
2. Farklı ulaşım türleri ve sistemleri arasında birlikte işlerliğin arttırılması
3. Taşıma alternatiflerinin arttırılması,
4. Kombine taşmacılığı uygun elektronik takip ve izleme sistemi geliştirilmesi,
5. Limanlar, iç limanlar, havaalanları arasındaki bağlantıların iyileştirilmesi ve bunların lojistik köylerle bağlantılarının iyileştirilmesi, verimli hale getirilmesi,
6. Özellikle trafik yönetiminin iyileştirilmesi amacıyla bilgi ve iletişim teknolojilerinden daha fazla faydalananması hedeflenmektedir.

Altyapıların kalitesini arttırabilmek için;
- Ulaştırma türlerinin teknik ve ekonomik açıdan en uygun yerlerde kullanıldığı,
- Alternatif ulaşım sistemleri kurmak için Ar-Ge çalışmalarının yapılması
- Bilgi ve iletişim sistemlerindeki gelişmelere paralel olarak otomatik taşıt kayıt ve kontrol sistemlerinin ve gerçek zamanlı karayolu trafik yönetim sistemlerinin geliştirilmesi
- Karayolu ağına tesis edilecek akıllı ulaşım sistemleri ile akıllı yollara uyum sağlayacak akıllı araç elektronik düzenlerinin kurulması, özellikle kaza anlarında araç ve konum bilgilerinin bir merkeze ileteileceği acil çağrı sistemlerinin kurulması gerekmektedir.

Trafik Kontrol Merkezi’nin kuruluş amacı İstanbul trafiğinin sürücü, yolcu ve yayalar açısından daha güvenli, erişilebilir olması için yol ve sürüş güvenliğini en üst seviyeye yükseltmektedir. Trafik Kontrol Merkezi, zaman ve maliyet açısından etkin bir trafik gözlem ve yönetim altyapısı kurmak, işletmek ve elde edilen veriler ile sürücü, yolcu ve yayaların İstanbul trafiğini en etkin, güvenli, çevreye duyarlı, çağdaş ihtiyaçlara cevap verecek bir şekilde kullanmasını sağlamak temel amacı olarak benimsemeyi görev edinmiştir.

Büyükşehirlerin her gün artan ulaşım problemlerinin çözümünde önemli bir unsur olan “Trafik Kontrol Merkezi” ITS (Akıllı Ulaşım Sistemleri) olarak adlandırılan gelişmiş yüksek teknoloji uygulamalarından faydalanarak, kentte meydana gelen anlık trafik akışı 24 saat gerçek zamanlı olarak izlenmekte ve kontrol edilebilmektedir.

Akıllı ulaşım ve sinyalizasyon sistemleri çalışmaları, Trafik Kontrol Merkezi ve bu merkeze bağlı Trafik Ölçüm ve Gözlem Sistemleri, Trafik Denetleme Sistemleri (EDS), Trafik Sinyalizasyon Sistemleri, ve Trafik Bilgilendireme Sistemlerinin işletilmesi ve bakım onarımını kapsamaktadır.
Şekil.6.Trafik Kontrol Merkezi

2.5. Lojistik Bilişim Teknolojileri


Şekil.7 Lojistik Bilgi Teknolojileri’nin haritası (Kaynak: warehows.org)
Lojistik Bilgi Sistemleri (Şekil.8), tedarik zinciri üzerinde yer alan şirketlerin her birinin kendi planlama veya operasyonel ihtiyaçlarını karşılayan, şirket içinde ve/veya dışındaki diğer ilişkili sistemler ile entegre çalışan yazılım sistemleridir. Burada entegrasyon olarak tanımlanan ilişki bilgi sistemleri arasındaki bilgi ve belge akış fonksiyonudur. Firmalar, çoğu kez bu yazılım sistemlerini ayrı ayrı satın alıp kullanmak yerine hepsini ya da çoğunu modüller olarak içeren entegre Kurumsal Kaynak Planlama (KKP) yazılımları kullanırlar.

Şekil.8 Lojistik Bilgi Sistemleri’nin haritası (Kaynak: warehows.org)

2.6. Operasyonel Lojistik Yönetimi

2.6.1 Tedarik Zinciri Lojistik Yönetimi (Supply Chain Logistics Management)

Tedarik zincirinin ve bu zincir içinde yer alan şirketlerin uzun dönemde performanslarını artırmak amacıyla, söz konusu şirketlere ilişkin üretim ve lojistik fonksiyonlarının birlikte yönetimidir.
2.6.2 Tam Zamanında Üretim/Teslimat (Just In Time Manufacturing and Delivery)
Çekme (sipariş) esaslı bir yaklaşım ile gerekli malzemenin, gereklen zaman ve miktarda, gereklen yerden alınıp, gereklen yere, gereklen zamanda ve istenilen koşullara uygun olarak üretimi ve teslimatına yönelik sistemdir.

2.6.3 Çapraz Sevkiyat (Cross Dock)
Depo alınına gelen ve giden ürünler için depolama faaliyeti oluşturmadan gruplama ve aktarmayı gerçekleştirenerek depolama hacminde tasarruf sağlama ve ürün akış hızını artırma çabasıdır. Ürünler çapraz sevkiyat alanında belirli bir süreden (12 veya 24 saat) daha az zaman kalmak durumundadır.

2.6.4 Yükleme Optimizasyonu (Loading Optimisation)
Yükleme ve boşaltma zamanından tasarruf etmek, işçilik maliyetlerini düşürmek ve/veya kabın/aracın kapasitesini en verimli biçimde kullanmak suretiyle taşıma maliyetlerini düşürmek üzere yüklerin, kaba/araca en etkin biçimde yerleştilmesidir.

2.6.5 Çağdaş Depo Tasarımı ve Yönetimi
Gereksinmeler doğrultusunda müşteri hizmet düzeyini artırırken lojistik maliyetleri düşürmeye yönelik maliyet etkin (cost effective) depo çözümleri oluşturulmaktadır.

2.6.6 Sürekli Gelişim ve İnovasyon
Şirkette tüm çalışanların katılımı ve toplam kalite anlayışı ile sürekli gelişim ve inovasyon ortamının yaratılmasıdır.

2.7. Afet Lojistiği
Afet ve acil durum lojistiği, insanları, kaynakları, yetenek ve bilgiyi, afetlerden etkilenmiş afetzedelere yardım etmek için etkin bir şekilde mobilize edebilen süreçler ve sistemlerden oluşur. Afet lojistiği aşamaları; Afet öncesi hazırlık, Afet müdahale süreci, Müdahale sonrası lojistik faaliyetler.

Afet Müdahale Sürecinde; Lojistik Faaliyetleri Ön değerlendirme ve ihtiyaç tespiti yapılmalıdır, Lojistik eylem planı yapılmalı ve uygulanmalıdır, Afetle müdahale sürecinin izlenmesi, değerlendirilmesi ve raporlanması gerekmektedir.
Afet Lojistiği planı oluşturularak Haberleşme, Taşımacılık, Depolama, Altyapı Hizmetleri, Geçici İskan Hizmetleri, Enkaz Kaldırma Hizmetleri, Dış Kuruluş Koordinasyonu, Personel Sağlık Hizmetleri başlıklarında bütün detaylar ayrıntılı bir şekilde incelenmelidir.

2.8. **Kentsel lojistik en iyi uygulama örnekleri**

2.8.1 **Londra**

Londra’da 2026 yılında 1,2 milyona çıkacağı ve bulunla birlikte 800,000 iş alanı oluşacağı tahmin edilmektedir. Aynı sürece ürün ve hizmet talepleri %12-15 oranında artması beklenmektedir. Londra’daki yük hareketliliğinden kaynaklanan yol tıkanıklık maliyeti en yüksek maliyet değerini vermektedir. Mevcut durumda %82 oranında yük taşımacılığı karayolu ile sağlanmaktadır. Yük taşımacılığı kullanılan tüm modlar için co2 emisyonlarının ve gürültünün azaltılması hedeflenmektedir. 2002 yılında Londra’daki %38 oranında NOx, %24 oranında PM10 ve %17 oranında CO2 emisyonu açığa çıkmıştır. Ağır taşıtlardan kaynaklanan yaralanmalı ve ölümlü kazalar da ciddi oranlardadır.

**Şekil. 9 Londra’daki Stratejik yük güzergahları (Transport for London, 2010)**

Londra’da en önemli ulaşım politikalarından biri yük taşımacılığının verimliliğini ve sürdürülebilirliğini arttırmaktır. Londra Yük Taşımacılığı Planı ile; emniyetli, güvenilir ve
etkin bir yük taşımacılığı faaliyetlerini yürüterek Londra’nın ekonomisini desteklemektedir. Bunu yaparken de diğer yol kullanıcılarnın ihtiyaçlarını, çevresel faktörleri ve Londra’da yaşayanların hayat kalitesinden ötür verilmemesine çalışılmaktadır.

Buna göre şu hedefler ortaya konulmuştur;

- Londra Yük Taşımacılığı Planı’nı geliştirmek
- Londra’da Sürdürülebilir Dağıtım Ortaklarının oluşturulmasını sağlamak
- Hizmet alan ve verenler arasındaki iletişimi sağlayan tecrübe alanına dayanarak yük taşımacılığına ilişkin çözümler üretmek

Uygulama:

Yük Taşımacılığı Planı; Londra’nın uzun dönemde ulaşım ihtiyaçlarını karşılayacak 8 temel öneri geliştirilmişdir;

- En iyi uygulamaları desteklemek
- Alt bölgeleme ile Yük Kalite Ortaklarının gelişimini desteklemek ve iletişimini arttırmak
- Yıllık Yük Verilerini Raporlamak
- Yük taşımacılığı eğitimleri programlarını düzenlemek
- Yük İşletmelerini Tanıma ve Geliştirme programları oluşturmak
- Güvenilirliği Arttırmak
- Londra’daki teslimatların güvenilirliğini artırarak ve yük faaliyetlerinin planlı ve kurallara uygun gerçekleştirilmesini sağlamak
- Sürdürülebilir dağıtımculğun düzenlenmesi
- Tedarik zincirinin yeniden düzenlenmesi ve daha ekonomik ve çevresel değişikliklerin planlanması
- Tedarik zincirinde konsolidasyon merkezlerinin düzenlenmesi (Londra Konsolidasyon Merkezi Projesi)

Yakit tüketimine bağlı yük taşımacılığının daha ekonomik ve çevreye duyarlı olarak düzenlenmesi (Londra Düşük Emisyon Bölgeleme Projesi)
Başlangıç ihtiyaçlarının neler olduğunu ortaya koyan paydaş görüşmeleri yapılarak yük taşmacılığına ilişkin vizyon ve hedefler ortaya konulmuştur.

12 adet yük birimi oluşturulmasıyla birlikte, 120 ayrı kurum ve işletmenin Londra Sürdürülebilir Dağıtımçılık adıyla tek bir çatı altında toplanmıştır.

Kurumlar şu özellikleri içermektedir;

- Önemli sanayi sektörleri (perakende satış; atık; inşaat; kurye ve parsel; yağ & kimyasaller; hizmet sektörleri)
- Stratejik yük kalite ortaklıkları (5 alt bölgeleme)
- Farklı modlarla yük taşımacılığı grupları (karayolu; demiryolu; denizyolu; havayolu)
- Özel uzmanlık grupları (çevre; planlama; iş; araç, teknoloji & yakıt, emniyet & güvenlik)
- İş Planı Koordinasyon Grubu (Denizyolları, Liman, Ulaşım, Ticaret ve Sanayi, Devlet Kurumları) (British Waterways; Port of London Authority; Environment Agency; Transport for London; Department of Trade and Industry; Association of London Government; Greater London Authority; Department for Industry; London Development Agency Government Office for London).

Yük Birimleri

Londra Ulaşım Birimi (Transport for London (TfL)) Londra’daki yük taşımacılığını geliştirecek 12 birim oluşturmuştur.

Bu yük birimleri şu konularla ilgili çalışmalar yürütmektedir;

- İlişkilerin kurulması, Londra’da alt bölgeler, işletmeler arasında iletişimin kurulması, Pilot proje ve çalışmalar geliştirilmesi, Veriye erişimin arttırılması, Yaygın kullanımına açık fırsatların ve yararların oluşturulması, Hızlı kazanımların sağlanması, İşletmeler arası sorumlulukların netleştirilmesi ile;

Yük davranışlarının nasıl gerçekleştiğini, Londra’daki etkileri ve yönetiminin nasıl gerçekleştireceği belirlenerek çözümlerin üretebileceği ortak akılların ortaya konulduğu ve Londra’nın gelişimini sağlayacak sürdürülebilir bir yük planlamasının oluşturulması amaçlanmaktadır.
2.8.2 Lyon

Lyon’da, devlet kurumları trafiğin yönetimi ve hava kalitesinden sorumludurlar. İki idari birim mecuttur; Ville de Lyon ve Grand Lyon. Bu iki kurum özellikle ağır taşıt özelinde hava kalitesini ve trafiğin yönetimini geliştirmeye yönelik çalışmaktadır.

Günümüz kadar en dikkate değer uygulamalar şunlardır;

2007 yılında Lyon’un tarihi bölgesinde (Presqu’île) 2007 yılından itibaren sevkiyat araçlarına yönelik yeni bir uygulama test edilmiştir. Saône, Rhône nehirlerinin yakınında doğu ve batı yönlerinde, Place des Terreaux’un yakınlarında kuzey yönünde ve Perrache Station’nın yakınlarında güney yönündeki çemberde sınırlandırma yapılmıştır. Sınırlandırma şu şekilde gerçekleştirilmektedir;

- Gündüz saatlerinde yüzeyi 29 m2 nin üzerinde olan araçların geçişi Yasaklanmıştır.
- Sevkiyat bölgelerine göre;
  - Giriş 30 dk ile sınırlandırılmıştır. o Sevkiyat/Teslimat plakalarının kullanımı zorunlu hale getirilmiştir.
  - Sevkiyat bölgelerine erişim sadece özel türdeki araçlar için izin verilmiştir. (kendi hesabına kiralama ve taşıma yapanlar için)
Şekil 11 Lyon yük noktaları (Only Lyon, 2011)

Kısa vadeli hedefler arasında 2011 yılında Rhône’nin sol yakasında bu türde bir uygulamanın genişletilmesi yer almaktadır. Orta vadede ise tüm Lyon şehrinde ve diğer kentlerde uygulamalar yapılabilir.


Bu planın çerçevesi Grand Lyon bölgesinin dışında 105 yerel yönetimi de içerisinde almaktadır.

Grand Lyon’da İklim Değişikliği Planı

Kyoto protokolünün uygulanmaya başlamasıyla birlikte, Grand Lyon kentsel otoriteleri sera gazlarının azaltılmasına yönelik çalışmalar başladi. İklim değişikliği planına göre, CO2 emisyonlarını 2020 yılına kadar %20 oranında, 2050 yılında ise %75 oranında azaltılması öngörülmüştür. Ayni zamanda 2020 yılı için enerji tüketiminin %20 oranında azaltılması hedeflenmiştir.

3 temel hedef mevcuttur;
Çevrenin korunması ve iklim değişikliğine yönelik uygulamaların yapılması

Yaşam kalitesini artırmak

İklim konulara bağlı olarak ekonomik gelişime katkıda bulunmak

Lyon çevrenin korunmasına yönelik uygulamaları başlıca uygulamalarının başında tutmaktadır. Bütün ilgili sektörlerin rol oynayacağı bir yönetimin oluşturulması planlanmaktadır.

Grand Lyon’da Gürültü Kirliliği Planı


2.8.3 Burgos (İspanya)

Şehirlerdeki temel faaliyet olan malların dağıtımı yaya odaklı gelişimi destekleyici şekilde yeni uygulamalar gerektirmektedir. Malların dağıtımı yapılırken ‘temiz bölge’de araç geçişi azaltılmalıdır. Bu bölgede çevreye daha az zarar verecek nitelikte araçlar hizmet vermelidir.

Temel hedefler şu şekilde sıralanabilir;

· ‘Temiz bölge’de araç geçişi azaltılması
· Bu bölgede çevreye daha az zarar veren yakıt türüne sahip araçları teşvik etmek
· Dağıtım alanlarının yeniden düzenlenmesi

Yenilikçi yaklaşımlar;

· Mal teslimi ve dağıtım planlarının optimizasyonu
· Sınırlı erişimin olduğu alanlarda temiz yakıtlı araçların kullanımı
· Teslimatların yönetiminde yeni teknolojiler
· Bilgi teknolojilerinin kullanımı.
Mal dağıtımları ve teslimat şekilleri kentlerde çok benzerdir. Burgos’ta, şehrin dışındaki merkez depolardan günlük olarak küçük kamyonetlerle şehir içinde dolanarak siparişleri teslim etmektedir. Bu türde dağıtımlara bağlı olarak oluşan problemler şu şekildedir;

· Farklı büyüklüklerde birçok araç taşıdıkları mala göre farklılık göstermektedir.

· Şehir çevresinde sirkülasyon ve tarihi yerlerdeki özel alanlara girişler trafik problemlerini arttırmaktadır.

-Yükleme- boşaltma süresince resmi olmayan çift sıra parklanma yapılması

-Teslimat araçlarının yayalaştırılmış alanlara girişi ve yayaları rahatsız etmesi

2.8.3.1 CIVITAS-CARAVEL Projesi


Faaliyetler şu şekilde yürütülecektir;

· Temiz bölgede malların dağıtımının optimizasyonu.

· Temiz bölge etrafındaki park alanlarının yükleme ve boşaltma için yeniden düzenlenmesi.

· Temiz bölgede oturan bölge sakindleri için yapılacak düzenlemeler.

· Temiz bölgedeki dağıtım için yeni uyarlamaların tasarlanması.

· Dağıtıcı, lojistik hizmet ve sanayi alanları arasındaki ilişki ve durumun analizi.
- Sosyal ve ekonomik fizibilite analizi ve yeni malların dağıtım sisteminin yeterli şekilde düzenlenmesi.
- Etkilenen bölgelerin tasarlaması ve ilgili paydaşların saptanması.
- Şehirdeki malların dağıtımı için yönetim kriterlerinin belirlenmesi.
- Malların dağıtımı için güzergahların, planların, ürünlerin ve alanların tasarımı.
- Temiz bölgede malların teslimatı için temiz araçların piyasaya sokulması.

İnovatif ve Yayılma Faaliyetleri
- Mal dağıtım stratejilerinin uygulanmaya geçebilmesi için toplum bilgilendirme kampanyaları yapılarak yüksek oranda kabul görmesi amaçlanmaktadır.

Eğitim faaliyetleri
- Eğitim faaliyetleri, çalıştayların düzenlenmesi.
- Operational training for system operators.

Değerlendirme
- Nitel ve nicel verilerle ölçümler yapılarak projenin değerlendirilmesi yapılacaktır.
Ölçümler yeni erişim kısıtlama sistemiyle bağlantılıdır ve gelecek yük dağıtımını merkezlerinde planın geliştirilmesine yöneliktir. Malların dağıtım sistemi, erişim kısıtlama sistemi veya trafik kontrol merkezi ile ilişkilidir. Caravel projesinde planın geliştirilmesi ve gelecek dağıtım merkezinin açılması (elektrik, sürdürülebilir araçlar) yer almaktadır. Değerlendirme sonuçları ile önemli bir farkındalık ve erişim sınırlaması ve yeni yük dağıtım merkezine yönelik yaşayan halkın görüşlerinin değişimi sağlanacaktır.
- Yeni yük dağıtım merkezi ile %88 oranında yaşayan halkın desteğiyle ölçümlerin uygulanması, %90’dan fazla mal dağıtım firmalarının sistemi desteklemesi.
- Cenova ve diğer şehirlerin iyi çözümlerinin transferi.
- Paydaşların süreç boyunca dahil edilmesi.
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