The wealth of knowledge accumulated during the 17th IRF World Meeting & Exhibition in Riyadh was the driving force behind our decision to launch the IRF Examiner as a freely available resource for the industry. With this tenth issue, the International Road Federation confirms its role as a leading provider of applied knowledge in areas of vital importance for the global community of road professionals.

As the road sector delivers increasingly sophisticated solutions addressing our societies new mobility needs, the availability of global knowledge resources such as those provided by IRF is now more important than ever. I invite you to make full use of these resources and the associated training programs delivered by IRF.

H.E. Eng. Abdullah A. Al-Mogbel
IRF Chairman

Roads are the world’s first “social network”. They are fundamental building blocks for human and economic development whose impacts transcend national borders. The benefits of investments in roads have shown how transformative an infrastructure they can be for a wide range of beneficiary communities. At the International Road Federation, we have tried to capture these connections with a simple slogan “Better Roads. Better World”. Since we were established 1948, our primary purpose has been to transfer the latest technologies and knowledge from those who have it to those who need it, and in doing so, promote an agenda of shared prosperity that flows from accessible, affordable and sustainable road networks. The IRF Examiner is an essential vehicle to this ambitious agenda.

C. Patrick Sankey
IRF President & CEO

Under its many guises, intelligent transport systems (ITS) are a key component of IRF’s “value proposition” to road stakeholders. With rising motorization rates, nations around the world are looking for options that will help better allocate the demand and supply for transport services and mitigate their negative impacts. From managed lane operations to electronic tolling, and from roadway data analytics to smart cities, IRF offers decision makers a global clearing house for best practices, processes, solutions and case studies at a time when the complexity of ITS solutions has grown exponentially.

IRF also offers a portfolio of courses and a core of world-class instructors who can deliver certified training with a particular focus on helping transitioning economies leapfrog their way to the most cost-effective and scalable options built around open standards. As the premier global executive and professional training organization in the world, I invite interested parties from the public, academic and private sectors to join our committees and events, and also to work with IRF for their ongoing research and continuing education programs.

Tom Antonissen
Senior Advisor for Europe & Central Asia
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MANAGED MOTORWAYS – UK AND AUSTRALIA, WORLDS APART?

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ABSTRACT
Managed Motorways (MM) has brought Intelligent Transport Systems from a ‘nice to have’ add-on facility to an integral part of a road network and is now an essential tool for a road network operator. MM forms the cornerstone of the UK Highways Agency’s Roads Programme. In Australia, the momentum behind MM/Freeways continues to build with more States developing delivery programmes. Whilst the aims within Australia and the UK are broadly similar – reduced congestion, more reliable journey times, reduced environmental impact from travel and improved safety – the approaches taken are markedly different. In Australia the basic building block is Coordinated Ramp Signalling, and the UK approach adds capacity by use of the emergency hard shoulder. These two approaches therefore appear fundamentally different – do they lead to different outcomes, do they need to be seen as opposing ways of working, or do they form complementary tools in the overall menu available to a network operator?

INTRODUCTION
The Managed Motorways concept first saw the light of day in England in 2006 in the guise of the M42 Active Traffic Management (ATM) Pilot, a scheme that drew heavily on best practice from around the world in achieving its aims of creating additional capacity by ‘sweating the asset’. Since the success of that Pilot, MM is firmly placed at the heart of the Highways Agency’s programme for managing and operating their road network. Across the world, Intelligent Transportation Systems (ITS) and MM have moved from being seen as a “nice to have” add-on facility to an integral part of a road network – they are now essential tool for road network operators.

WHAT’S THE PROBLEM?
In the most simplistic terms, roads become congested when there is too much traffic for the available capacity – either due to sheer volume of traffic or when capacity is restricted, for example when an accident occurs. Other issues such as merging and weaving traffic cause turbulence and upset the natural balance of a free flowing system.

The concepts behind Managed Motorways and Freeways are designed to provide a set of tools for either stopping these circumstances from occurring or managing their impacts when they do.

MANAGED FREEWAYS IN AUSTRALIA
The most comprehensive Managed Freeway (MF) scheme in Australia is the M1 around Melbourne – a 75 km section of the Monash – CityLink – West Gate Freeway which started to be operated in December 2009. The system includes coordinated ramp signals on more than 60 on ramps, lane control and variable speed limit signs and electronic message signs (including real-time traffic information) with wireless detectors and CCTV cameras, all managed through a new control system. The results from the M1 are impressive and led to the development of the next scheme in Victoria, the M80. Other States are following suit using the VicRoads example as their model.

VicRoads’ Managed Freeways Guidelines (1) state that the key principle behind Managed Freeways is “Planning for Operations” with a focus on improving reliability.
The toolkit available for Managed Freeway operations includes:

- **Intelligence** – such as Vehicle detection equipment, CCTV, Help Phones, etc;
- **Control** – Freeway Ramp Signals, Variable Speed limits and Lane Use Management;
- **Information** – including Real time information signs, Variable Message Signs, etc;
- **“Foundation Systems and Infrastructure”** – including a control system, power system, Traffic Management Centre and a communications system.

**Figure 1: Managed Freeway in Melbourne**

The core building block within a Managed Freeway is Coordinated Ramp Signals (CRS), which provides the greatest benefits. The key traffic parameter for CRS is occupancy. CRS is used to manage the flow of traffic onto the Freeway to prevent capacity being exceeded and breaking up vehicle platoons – so delaying or preventing flow breakdown and overloading merges. Lane control signals are used to manage incidents by indicating closed lanes ahead and variable speed limits are used to reduce speeds during incident management and also during congestion to increase capacity.

McHugh et al (2) conclude that “Based on contemporary traffic flow theory, applied research to the WA (Western Australian) network, and operational experience from other jurisdictions, Main Roads has determined that coordinated ramp signaling is the most effective management tool for achieving and sustaining the existing freeway capacity and reducing the likelihood of flow breakdown, whilst also facilitating system recovery if it does occur following an incident”.

According to the VicRoads publication “Managed Freeways, Freeways Ramp Signals Handbook” (3), Freeway ramp signals are provided to “optimise freeway throughput, travel speed and travel time reliability” and to make travel safer. The impact of traffic joining the Freeway is regulated by the ramp signals, and so the potential for flow breakdown is reduced, which in turn reduces congestion. This reduction in congestion and the associated stop/start conditions results in fewer accidents as do the reduction in lane changing and weaving at merges.

Ramp signals have been in use for a long time – the first trial in the UK was in 1986 on the M6 motorway, whilst in North America they have been in use since the early 1960s. These installations have tended to work “locally” to treat isolated instances of congestion and to improve flow through the junction itself – reducing, in the UK, journey times through congested junctions by an average of 13% and increasing capacity through the junction by 5-7%.

Where the Managed Freeway system comes into its own is the coordination of these signals across a number of ramps to deal with a downstream bottleneck rather than local congestion - treating the Freeway as a system with multiple “injection” points and monitoring the flow along an extended length (typically involving between 6 and 10 entry ramps), allowing entry in a controlled and coordinated manner. The system is dynamic and continually monitors flow – on the main Freeway and the entry and exit ramps - across its entire length regulating the incoming flow to match the capacity of a downstream “critical bottleneck” which could be a number of interchanges away.

This coordination of ramp signals requires the ramps to be sufficiently close each other to enable the controlling of the traffic joining the Freeway to have a positive impact on the overall flow. The configuration of the HERO algorithm used in Melbourne is capable of managing bottleneck locations up to 5km from the nearest on ramp; it also smoothes out any oscillations between the traffic entering via the on ramp and the time it takes to arrive at the critical bottleneck. A number of other factors also have an influence on how effective the system is, including the distance between ramps and the storage capacity of the ramps themselves. A number of ramps were lengthened and/or widened on the M1 to provide sufficient storage length and also discharge capacity at the stop line.

**MANAGED MOTORWAYS IN ENGLAND**

The path to the current generation of MM in England starts before the ATM Pilot with the introduction of the
Controlled Motorway (CM) on the M25 near Heathrow airport. The M25 changed driver behavior and the perception of traffic control on motorways through the use of speed limits that varied in response to traffic conditions – effectively conditioning drivers to drive slower in order to experience a smoother journey. Whilst this was, and remains, an operating environment that relies on technology it represents a fundamental breakthrough in adding driver behavior and education into the more traditional ‘toolkit’ of infrastructure and technology.

Prior to CM, motorway signals displayed advisory speed limits and were generally used to manage incidents – gantries were provided on sections of motorway that had 4 lanes with the majority of the network served by a single matrix mounted on a post. The CM project introduced variable mandatory speed limits linked to an inductive loop detection system under the control of a new algorithm, which enabled traffic speeds to be controlled and ‘start-stop’ behaviour reduced. The aim of the system being to slow traffic down before it reached the point of flow breakdown and hence prevent, or delay that status from occurring. This delay and reduction in flow breakdown created an increase in capacity.

The breakthrough achieved by CM was to show drivers that if they regulated their speed as indicated on the signals above the lanes, and then congestion reduced as a result. A clearly visible change in behavior and attitudes occurred as a result of the variable speed limits. An integral element of CM was a speed enforcement system, achieving a system capable of delivering evidence of sufficient quality and reliability to be used in a Court of Law, provide its own, technical and organizational, challenges.

The ATM Pilot was conceived following the production in 2000 of the Highways Agency’s (HA) ‘Transport 2010: The 10 Year Plan’ which aimed to ease congestion, reduce the number and impact of accidents and provide better information about conditions on the network. The HA undertook a review of best practice around the world and the ATM concept drew heavily on emerging practices within the Netherlands and Germany. The systems in NL included the Spittstrook, which was already in use on the A28 around Utrecht and used the hard shoulder, in a controlled manner, to provide additional capacity and the plus lanes, which also introduced additional capacity during peak times.

Various “Operational Regimes” were considered and the one, which promised the greatest benefits, was the dynamic use of the hard shoulder – using it as an additional traffic lane to manage incidents and during periods of congestion.

An extensive series of workshops attended by safety specialists as well as experienced practitioners within the various disciplines (civils, operational, systems, ITS, etc) was used to develop a list of hazards along with the potential probability, severity and likelihood associated with each hazard. The workshops were informed by data, where available and professional judgement as well as various hazard and operability (HAZOP) exercises.

The methodology uses three parameters (probability, likelihood / frequency and severity) to enable the calculation of a safety risk score for a hazard which is defined as either an ‘event’ or ‘state’. A state is a hazard that exists over a period of time whereas an event occurs in a moment of time – for example a vehicle stopping or an accident is an event, whilst a weather condition is a state. The hazard log uses a logarithmic scale, thus a score increase of one represents a factor of ten increase in risk – small changes in scores result in large percentage changes in risk e.g. a 0.5 increase in the hazard score represents a 216% increase in risk. When added together the resultant score for each parameter represents the total risk score associated with the hazard.

A baseline of a dual three lane motorway with hard shoulder (D3M) was developed with the scores for the new Operational Regimes then compared against that baseline to determine whether the proposed regimes represented an increase or decrease in overall risk.

The output from the analysis was used to inform the design of the scheme(s) – such that design features were used to mitigate against the effects of the various hazards. The process and scores were ratified as part of the M42MM and Birmingham Box MM (BBMM) projects and has been used in the development of the MM All Lane Running concept and programme.
The ATM Pilot became operational in September 2006; the operational regimes were facilitated by variable mandatory speed limits as used on the M25 CM and underpinned by a comprehensive risk and hazard analysis. The results were immediate and impressive – data was gathered through an extensive monitoring programme and the results have been well documented.

Using the growing bank of evidence and data from the various MM schemes, the HA continued its journey to create additional capacity using the existing carriageway along with operational regimes and Managed Motorways All Lane Running (MMALR) was the result. MMALR turns the existing hard shoulder into a traffic lane within an environment where all lanes can be controlled using variable speeds, lane closures, variable messages and CCTV. The first MMALR scheme should be operational in 2014.

**Figure 3: Managed Motorways All Lane Running as Proposed for use in England**

ARE THEY WORLDS APART?

The results from the M1 in Victoria and from the M42 in England clearly demonstrate that both systems work; they have both achieved their objectives and provide a leap forward in road network operations. Are they mutually exclusive though? There is an element of not comparing ‘apples with apples’ – whilst both have the same label of Managed Motorways/Freeways, there are some significant differences between the two networks, which have driven the approaches to be adopted.

The HA’s approach was to achieve more reliable journey times by ‘sweating the asset’ and delaying the need to widen the motorway network. The English motorway network is predominantly an inter-urban network with junctions spaced, on average, more than 10 km apart (although the spacings on the M42 Pilot sections were much shorter) and with relatively narrow and short entry ramps. Much of the English motorway network is inter-urban in nature whereas the Melbourne network is more urban in nature.

The freeway around Melbourne has 62 ramps, spaced between 800 m and 4.5 km apart, many of which were widened and/or lengthened in order to facilitate the effective operation of CRS; the CRS approach is to use Occupancy as the key parameter.

Both approaches use the core principles of ITS as a tool for network operations:

- **Detection** – understanding what is happening on the network.
- **Analysis and decision making** – systems and people using data to understand the impact of what is happening; is it normal? If not then is it significantly different to warrant an intervention? If so then what interventions are available and what impact will they have? The algorithms at the heart of CRS use control system logic to balance the inflow of traffic from ramps automatically, in real time.
- **Information and instructions** – informing users about what is happening, providing potential choices or instructing them to do or not do something.
- **Communications** – either via cables, wireless, or a combination.
- **Driver behaviour** – understanding how drivers are likely to respond to various scenarios/circumstances and also to the interventions from the network operator. For example, for variable speed limits to be effective is an enforcement system necessary/desirable?
- **Infrastructure** – this “system” depends upon a level of infrastructure to enable it to function, including gantries, masts, equipment cabinets, ducted networks/chambers, safety barriers, power supply networks, and control/management centers.

Each approach has its merits and each could benefit from considering how and why the other has been so successful. There is a common approach to incident management – through the use of lane based signaling, variable speed limits and a detection system; this is underpinned by a real desire to actively manage the road network in a safe and efficient way. The approach to MF described in McHugh et al [2] adopts the operational safety risk management approach developed by the HA suggesting that alignment of approach has begun and is tangible.

There are key differences, which could become a catalyst for further development in each country. The HA’s journey to improved driver behavior and compliance and the “asset sweating” approach could lead to additional benefits on the Australian network; similarly, the coordinated approach to ramp signaling adopted in Australia could bring benefits on parts of the HA’s network, particularly where junctions are closely spaced and ramp storage can be provided.
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DEMONSTRATING NEXT GENERATION COOPERATIVE TRAFFIC CONTROL FOR DAY 1 COOPERATIVE ITS (C-ITS) APPLICATIONS. COMPASS4D VERONA PILOT SITE

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ABSTRACT

Compass4D (Cooperative Mobility Pilot on Safety and Sustainability Services for Deployment) is a 3-year EC-funded 10MEUR project under the programme of Competitiveness and Innovation (CIP) launched on January 1st, 2013. Its main objective is to target the improvement of road safety, increase energy efficiency and reduce congestion for road transport. These goals will be achieved by the concrete and sustainable deployment of Cooperative Intelligent Transport Systems in 7 Pilot Sites located in 7 European cities.

This paper will present details of the Verona Pilot Site that will enable the demonstration of the Compass4D services when a dangerous situation occurs at intersection, the Road Hazard Warning (RHW) that will give advice to reduce incidents by warning drivers about queuing traffic in blind spots, or suddenly breaking vehicles ahead, and the Energy Efficient Intersection Service (EEIS) that will provide users with indications about a fuel-efficient and comfortable speed profile crossing an intersection.

INTRODUCTION

Key Driving force behind Compass4D

The key driving force behind Compass4D (1) is to deploy cooperative Intelligent Transport Systems (ITS) to improve road safety, as well as energy efficiency of the road transport (2). In 2010, road traffic accidents caused more than 30,000 lives lost in Europe. Major reductions in casualties have been seen in recent years as a result of safety awareness, safer vehicles, infrastructure and legislation. Cooperative solutions can further help reducing incidents by increasing the situation awareness of the driver and influencing their behaviour.

Road congestion is increasing while road transport is the second biggest source of greenhouse gas emissions in the European Union (EU). It contributes about one-fifth of the EU’s total emissions of carbon dioxide (CO2). The European Union policy relating to the environment and protection of natural resources has been very active in the last years, and has now become a globally recognized issue. A range of measures has been made available to European member states (MS) ranging from legislation to financial instruments. Member states are required to meet stringent limits with regard to CO2 emissions, and pollutants within their cities. In response to emissions that exceed the set limits, member states must draw up action plans indicating the measures to be taken, in order to reduce that risk and to limit the duration of such an occurrence.

To respond to these challenges and pave the way for all European cities and road operators, the City of Verona along with six European cities/regions (Bordeaux, Copenhagen, Eindhoven-Helmond, Newcastle, Thessaloniki and Vigo) have united their forces in addressing road safety issues, traffic efficiency problems and the negative environmental impacts that road transport currently brings. These cities
together with the rest of the industrial and research partners from the Compass4D consortium strongly believe that cooperative mobility solutions can bring benefits to the key stakeholders and improve the lives of their citizens.

At the same time European countries and cities are facing challenging financial circumstances. Cooperative mobility solutions have the potential to improve the utilization of existing infrastructure, making them very cost effective compared to infrastructure extensions. However even the money for ITS based mobility investments is scarce, and every solution needs to be cost optimized. For the cooperative mobility solutions, this means that they need to be globally harmonized in order to obtain markets of scale. Therefore Compass4D pilot plans to work closely with their US and Japanese associates to ensure that the deployed cooperative mobility solutions will not only follow the latest global developments in this field, but also will actively drive them. This work will be done in a close cooperation with the already established EU-US Task Force.

Another important consideration prior to the real deployment of cooperative solutions is proving to key stakeholders that cooperative services do have a positive business case, and that all other deployment barriers have been removed.

**Key Objectives**

Besides the project’s objectives, the Verona Pilot Site aim to achieve some specific objectives related to the following topics:

- To reduce the overall delay, waiting times in traffic through enhancements adaption and through the introduction of novel cooperative telematics applications
- Reducing pollution generated by traffic density, by adopting an optimum traffic strategy, in order to give good traffic info for traffic participants, and to lower environmental impacts
- Positive side effects are the generation of higher comfort for the driver and passenger and the improvement of traffic safety. With a harmonized traffic flow the occurrences of accidents is decreasing

**INTELLIGENT TRANSPORTATION SYSTEMS IN VERONA, PILOT SITE DESCRIPTION AND PROPOSED COMPASS4D SERVICES/ARCHITECTURE**

**Existing Intelligent Transportation Systems**

Verona is located in the Veneto region, northern Italy, with approx. 265,000 inhabitants and is one of the seven major cities of the region. It is the second largest city municipality in the region and the third of northeast Italy. With respect to ITS, Verona city has already introduced a complex and fully integrated advanced traffic management platform (3) in the traffic management centre (TMC). Here, autonomous ITS and other applications (4) exchange data and are coordinated by a higher level subsystem that can directly be used for the Compass4D project. The Verona existing systems include:

OMNIA (5), an ITS platform which supports an open architecture whereby any system can be integrated within the platform independently of the supplier, product or technology. It acquires all traffic measures and stores it in a central system archive together with their estimated statistical profile such as traffic volumes, speed, etc. and traffic related data (e.g. signal plan, clearance capacity, turning proportions). There are more than 150 intersections in Verona (Figure 1) and all are connected to Omnia. The Verona Traffic systems implement both an actuation and an adaptive plan.

MISTIC (6) is another information mobility platform or Town Supervisor for cooperative traffic monitoring in the TMC. It:

- Integrates data from legacy systems
- Supplies real-time information on multiple communication channels
- Manages in real-time and forecast traffic model
- Operates according to EU standards (e.g. DATEX 1-2, TPEG, RDS-TMC)

**UTOPIA (7)**, a traffic management control system is already in place providing adaptive traffic control strategies. There are:

- 31 CCTV cameras on 30 traffic light intersections for traffic monitoring
- 52 variable message signs in the urban area - for parking information (urban), traffic information and collective routing

**Figure 1: Verona’s Mobility Supervisor**
Mobile service ‘veronamobile.it’, providing the following services: parking, traffic incidents, events, bike sharing, and information for disabled people, meteorological information, ZTL (traffic limited zone) and PMV

Figure 2: Existing Its Systems in Verona

Compass4D Pilot Site

As two communication technologies will be used, two city layouts will be considered. The first one will be concentrated in Verona city centre, with focus on the main corridors and arteries where the cooperative RSUs are going to be installed. On the other hand, the second layout includes the whole urban area and will be used by devices using LTE communication.

In summary, 25 cooperative ITS 5G compliant RSUs will be installed along with OBU's for 20 vehicles, 2 cameras for the safety application, and other 30 vehicles will be selected by the city of Verona to make tests using smart phones or tablets that use LTE communication. This latter option will enable the city to provide cooperative services also in the road network not covered by ITS G5 communication.

Services

The efficiency and safety applications that will be deployed and piloted in Verona are listed according to the city’s priorities. These applications are:

- The Energy Efficient Intersection Service (EEIS) aims to reduce energy use and vehicle emissions at signalised intersections. The major advantage of a cooperative EEIS using infrastructure-to-vehicle communication is the availability of signal phase and timing information (SPAT) in the vehicle. Presenting this information to drivers enables them to anticipate the current and upcoming traffic light state.

- The Road Hazard Warning (RHW) service aims to reduce incidents by sending warning messages to drivers to raise their attention level and inform them about appropriate behaviour. The advantage of a cooperative RHW service using infrastructure to vehicle communication is twofold. First, the replacement of expensive vehicle sensors by cooperative technology enables vehicles without such sensors to be aware of road hazards. Second, the service has already an impact with low market penetration as the hazards are detected and announced by the infrastructure. Note that in several cases the RHW service could replace conventional road hazard warning signs. The general advantages of the RHW service are: timely and continuous availability of road hazard information, reduction of delays and false alarms, and spatial and temporal flexibility. Hazards will be classified into static and dynamic depending on their spatial and temporal properties.

- The Red Light Violation Warning (RLVW) service aims to increase drivers’ alertness at signalised intersections to reduce the number of accidents at signalised intersection or reduce the impact of accidents in case they still happen. Although the focus of the service is on red light violation it also addresses situations involving emergency vehicles as well as right of way rules at signalised intersections in a more general sense. The advantage of a cooperative RLVW service using infrastructure-to-vehicle communication over conventional repressive solutions is its interference before instead of after an event occurs.

Architecture

The Verona Pilot Site architecture will be based on the Compass4D Reference Architecture (8) and will be distributed into three main components: On-board Units (OBU), Road Side Units (RSU) and a Back Office (BO) interconnected using different communication Technologies such as LTE, ITS G5 and conventional wired links.

Applications described before, will be supported by the exchange of well-known ITS-related messages (i.e. CAM, DENM, SPAT, TOPO) and additional software facilities developed for the different use cases considered in the project. The following picture summarizes, in a simple way, the components included in the architecture and their interconnections.
**Expected outcomes and conclusions**

In order to improve the urban mobility, based on the European Commission agenda in relation to the national strategies for ITS directives, Verona is moving fast to give answers to the new challenges that have emerged in recent years with respect to climate change, energy policy, air quality legislation and the difficulties of tackling congestions. In October 2008 the city of Verona joined the Covenant of Mayors, sponsored by the European Commission as part of the campaign for sustainable energy in Europe. In April 2011, it adopted the environmental energy plan, which contains guidelines and strategic objectives in the field of energy.

In October 2011, it approved the action plan for air quality and remediation, based on the result of two years of work of the municipal offices, with aid of the technical and scientific support of the University of Trento, ARPAV of Health Units, and 17 municipalities that have joined the agreement. The plan provides the adoption of structural measures to counter air pollution. Among many factors considered, one of the main things taken into consideration was mobility. In addition, open data mechanisms are already implemented by the city in order to encourage the participations of the citizens to access public information and used it for their own benefit or to develop new applications for the community. In particular, this latter potential benefit provides also the creation of new jobs or companies interesting in leveraging on such data to produce novel services.

In summary, Compass4D pilot site will deliver not only technical results concerning the reduction of CO2 or energy consumption but also recommendations for potential deployments in cities with similar characteristics or even bigger cities willing to take experience of Verona and extend it to a larger audience. Moreover, as the pilot site is using two types of communication (ITS G5 and LTE) for its services, benefits from the use of both technologies will be studied with a “whole life – whole system” approach, providing also an input to the business plans that the project intend to develop. During the implementation phase from the experiences that will be gained from this project an input to the ETSI (European standardization body) particularly related to SPAT (Signal Phase and Time) which is still in the phase of development will be provided. This project is also expected to bring benefits to city in terms of traffic efficiency, safety as the applications to be deployed have these main specific targets.

Furthermore, exploitation is also an important output of the project, since it is intended by the consortium to raise the attention, not only form the ITS community, but also to the whole chain of stakeholders involved in the deployment of ITS in a certain city, region or a country and even educational institutions interested in performing research on mobility aspects.

It is worth mentioning also another important aspect, which are the behavioural changes that might happen in users using the integrated system. Having a clear view of how user acceptance is and how the user interacts with the applications, are vital for the succeed and continuation of the deployment, specially, when C-ITS applications are intended to become available to a broader amount of people.

Finally, next steps of the pilot site are the development of the architecture for the intended services, and then start the operational phase that is intended to last 1 year, ending in December 2015.
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TRAVEL TIME RELIABILITY MEASUREMENT SENSITIVITY TO DATA SOURCE SELECTION

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ABSTRACT
Traffic congestion and associated impacts pose major concerns to the public. Although the concept of reliability is relatively new in transportation operations compared to other engineering discipline it is becoming increasingly important. Among all reliability measures in transportation system, travel time reliability is an increasing concern of both travelers and authorities.

This paper investigates the impact of data source selection on travel time reliability assessment. One years data from two independent sources, probe and Bluetooth, on a major congested freeway corridor in Maryland have been used for a travel time reliability analysis. Bluetooth sensors were permanently installed on multiple points along a corridor and probe data is provided by INRIX. Several travel time reliability measures were studied. Results show that some measures are more sensitive to the data source than others. It is also shown that sensitivity to data source decreases by increasing the size of time interval window.

INTRODUCTION
Traffic congestion and associated impacts such as air pollution pose major concerns to the public. Average travel times used to be the main performance measure as the basis of highway system performance measures. Due to the highly dynamic nature of traffic, the average often does not tell the whole story. In recent years, the concept of travel time reliability is proposed to measure the level of congestion and has gained interest among researchers and practitioners, as it better represents a commuter’s experience than a simple average travel time. Empirical studies indicate that travel time reliability plays a vital role in traveler’s route choice decisions under circumstances in which they are uncertain about the outcome of their decision (1). Travelers prefer reliable but on average longer route to faster route with higher uncertainty (2). Federal Highway Administration defines travel time reliability as ‘the consistency or dependability in travel times, as measured from day-to-day and/or across different times of the day.’ Several different criteria have been proposed to measure travel time reliability with no undisputed opinion on a single optimal measure. Most of these performance measures are related to the property of day-to-day travel time distribution. The wider the distribution, the more unreliable the travel time is (2).

Travel time reliability has been studied through a significant amount of research sponsored by the Strategic Highway Research Program 2 (SHRP2) and FHWA (3). The applications of travel time reliability concept...
range from traffic operation to long term transportation planning procedures. The annual Urban Mobility Report published by Texas Transposition Institute applies reliability measures to address the nation’s urban congestion problems (4). In 2012, the Maryland State Highway Administration published its first State Highway Mobility Report (5).

This study investigates the impact of data source on travel time reliability assessments by comparing travel time data obtained from Bluetooth and probe as two independent sources. The studied area covers I-270 northbound in Maryland from I-495 junction to exit 18, where both INRIX and permanently installed Bluetooth sensors provided travel time data for the entire year of 2012. A statistical method is carefully selected to assess the impact of data source on travel time reliability measurements. The rest of the paper gives a brief description of existing travel time reliability measurements followed by a discussion on data sources used in the case study and the methodologies to derive travel time from each source. Then, a statistical method is proposed to compare different reliability performance measures.

TRAVEL TIME RELIABILITY MEASUREMENTS

Although a significant amount of research has focused on travel time reliability and have proposed several reliability measures in the literature, there is a hot debate on which is the most effective one. A study by Lomax et al. provides a comprehensive review on existing travel time reliability measures (6). A report by the FHWA indicates that although reliability measure must have technical merit, it also must be easily understood by non-technical audiences (7). Finding an effective measure that provides the best understanding of existing traffic conditions is critical to travelers and transportation decision makers alike. This section briefly reviews some common reliability measures. Based on a study by J. Van Lint, et al. (2), travel time reliability measures are classified into four categories: 1) statistical range methods; 2) buffer time methods; 3) "tardy-trip" indicators; 4) probabilistic measures.

Statistical Range Measures

Statistical range methods interpret travel time reliability using some basic statistical concepts. This type of methods is easy to understand for statisticians, but most are difficult to be explained to nontechnical audiences.

Buffer Time Methods

Different from statistical methods, an average traveler can comprehend the buffer time concept as it often relates to the way travelers make route choice decisions. It measures the extra percentage of travel time that travelers should plan for their trip to ensure on-time arrival.

Tardy Trip Indicators

Tardy trip indicators emphasize the unreliability by using the amount of trips that lead to late arrivals. The Misery Index (MI), for example, is the average travel time of the 20% worst trips minus average travel time of the total trips and divided by the average travel time. This method focuses on the extra delays during the worst day-of-the-week.

Probabilistic Measures

Probabilistic measures calculate the probability that the observed travel times are larger than n times some predefined travel time threshold, for example, median travel time on a given time-of-day, or day-of-the-week.

DATA DESCRIPTION

Data Sources

Travel time reliability index is measured based on the underlying distribution of travel time on a segment over time. Effective calculation of such index requires accurate and high quality data. This study focuses on the impact of selecting INRIX and Bluetooth data on travel time reliability assessments. A section of Interstate 270 (I-270) northbound (Figure 1), which is a busy freeway corridor, is selected as the location for the case study. This segment has uninterrupted coverage of both Bluetooth and INRIX data 24 hours per day and 365 days a year. To compare travel time reliability assessment based on these two data sources, the case study is performed on a 17.89 miles long corridor covering the portion of I-270 northbound starting from I-495 junction and ending at exit 18. I-270 is an auxiliary Interstate Highway in the State of Maryland. The studied portion of I-270 consists of a local-express lane configuration as well as high-occupancy vehicle lanes that are in operation during afternoon peak hours (3:30 pm – 6:30 pm).

Figure 1: A Case Study
Table 1 provides the basic information for the studied segment. The INRIX data are reported on Traffic Message Channel (TMC) location codes, which is an industry standard developed and maintained by the leading electronic mapping vendors to uniquely define road segments(8). The entire corridor is covered by 25 TMC's with different lengths. Bluetooth data is extracted from two Bluetooth sensors (the first sensor MD_I270E_001 and the last sensor MD_I270_016). The first Bluetooth sensor is located 0.6 mile north of the start of the first TMC, while the last Bluetooth sensor is located 0.86 mile south of the end of the last TMC. The collected Bluetooth travel time is adjusted to match with the INRIX data based on the path length difference. The following briefly describes the procedure to collect and process the Bluetooth and INRIX data.

Table 1: Sensor and TMC Information for I-270 Study Area

<table>
<thead>
<tr>
<th>Bluetooth ID</th>
<th>Sensor Location</th>
<th>TMC_ID</th>
<th>Length(mile)</th>
<th>Endpoint(1)</th>
<th>Endpoint(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I270E_001</td>
<td>39.03</td>
<td>-77.11</td>
<td>1.08</td>
<td>39.0234</td>
<td>-77.1062</td>
</tr>
<tr>
<td></td>
<td>39.0301</td>
<td>-77.1225</td>
<td></td>
<td>39.0301</td>
<td>-77.1225</td>
</tr>
<tr>
<td>I270E_003</td>
<td>39.0301</td>
<td>-77.1225</td>
<td></td>
<td>39.0301</td>
<td>-77.1225</td>
</tr>
<tr>
<td>I270E_004</td>
<td>39.0324</td>
<td>-77.1365</td>
<td></td>
<td>39.0324</td>
<td>-77.1365</td>
</tr>
<tr>
<td>I270E_005</td>
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<td>-77.1365</td>
<td></td>
<td>39.0324</td>
<td>-77.1365</td>
</tr>
<tr>
<td>I270E_006</td>
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<td>-77.1365</td>
<td></td>
<td>39.0324</td>
<td>-77.1365</td>
</tr>
<tr>
<td>I270E_007</td>
<td>39.0324</td>
<td>-77.1365</td>
<td></td>
<td>39.0324</td>
<td>-77.1365</td>
</tr>
<tr>
<td>I270E_008</td>
<td>39.0324</td>
<td>-77.1365</td>
<td></td>
<td>39.0324</td>
<td>-77.1365</td>
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<tr>
<td>I270E_009</td>
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<td></td>
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</tr>
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<td>I270E_010</td>
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<td>-77.1365</td>
<td></td>
<td>39.0324</td>
<td>-77.1365</td>
</tr>
<tr>
<td>I270E_011</td>
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<td></td>
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<td>-77.1365</td>
</tr>
<tr>
<td>I270E_012</td>
<td>39.0324</td>
<td>-77.1365</td>
<td></td>
<td>39.0324</td>
<td>-77.1365</td>
</tr>
<tr>
<td>I270E_013</td>
<td>39.0324</td>
<td>-77.1365</td>
<td></td>
<td>39.0324</td>
<td>-77.1365</td>
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<td>I270E_015</td>
<td>39.0324</td>
<td>-77.1365</td>
<td></td>
<td>39.0324</td>
<td>-77.1365</td>
</tr>
</tbody>
</table>

Bluetooth Data

Bluetooth as an open, wireless communication platform enables digital devices interconnect with each other using short-range wireless communications. Many computers, mobile phones, car radios and dashboard systems, PDAs, headsets, or other personal devices come equipped with Bluetooth wireless capability to communicate with other Bluetooth enabled devices anywhere from 1 m to about 100 m. In the context of vehicle travel time collection, the Bluetooth detector captures the electronic identifier, or tag, called Machine Access Control (MAC) address, in each Bluetooth enabled devices and places a timestamp when the vehicle enters the detection range of the sensor. As the same vehicle passes subsequent detectors, the detected MAC address can be matched. The difference of the detection time for the same vehicle is the time used to traverse this segment between the two detectors. Bluetooth technique requires at least two detectors to obtain travel time data. The raw data are MAC addresses along with their collection time. More than 5.5 million MAC addresses were reported by the sensors at the beginning and end of the study area for 2012. A four-step filtering algorithm proposed by Haghani, et al. (9) is utilized to extract travel time from the pool of Bluetooth observations.

INRIX Data

The company INRIX is a private-sector travel time data provider that derives travel times from its smart driver network, which aggregates traffic data from probe vehicles and traditional sensor sources. The probe vehicles utilized include: taxis, airport shuttles, service delivery vans, long-haul trucks, consumer vehicles, and GPS enabled consumer smartphones and so on. The data fusion methods are proprietary and travel times are reported on TMC segments.

The study area is a path consisting of 25 TMC codes. In order to calculate path travel times in different intervals that are directly comparable with Bluetooth data points, data from all TMC’s must be consolidated. Bluetooth observations are time tagged at the end sensor, so a backtracking algorithm is required to generate equivalent INRIX record per each Bluetooth observation. The INRIX path records are then aggregated in desired intervals. More than 2.6 million INRIX travel time records were processed to get the results. Details of this method can be found in Hamedi, et al. (10).

Travel Time Data Distribution

As travel time patterns during weekend are significantly different from weekdays, this study has only focused on travel time reliability measures during weekdays. As a result, a total of 260 days travel time data in 2012 are selected. Figure 2 (a) and (b) depict weekday Bluetooth and INRIX travel times for the entire year in 15 minute intervals. The scatter plots provide a straightforward illustration of travel time distributions over the entire year. It can be seen from this plot that the variations of Bluetooth data is higher than that of INRIX data, especially during the afternoon peak hours. To better understand the distribution of the data, box-and-whisker plot of Bluetooth and INRIX travel times data (without outliers) are provided through Figure 2 (c) and (d). The bottom and top of the blue box are the first and third quartiles of the travel time data, and the black band inside the box is the median. During non-peak hours, the first and third quartiles are close to the median with relatively smaller variations of travel time. During peak hours (3pm to 7 pm), the variations of travel time grow with about 10 minutes bandwidth (variations) between the first and third quartiles.
METHODOLOGY

Real-world data is subject to measurement error and the errors associated with different data collection methods could be different due to the uniqueness of data collection and processing procedures. As indicated in Figure 2, the travel time collected from Bluetooth sensors are more sparsely distributed compared with the INRIX data. Therefore, it is critical to test if measures based on different data sources would be different.

The Maryland State Highway Administration utilized the Travel Time Index (TTI) and Planning Time Index (PTI) to quantify congestions in their 2012 mobility report [5]. The TTI denotes the ratio of actual travel time to the ideal or free flow travel time, while the PTI represents the percentage of time compare with free flow travel time a traveler should allow to make sure on time arrival by considering the worst conditions. FIGURE 3 depicts the hourly TTI and PTI measures based on Bluetooth and INRIX data. Values for both measures begin to increase at 3:00 pm and move back to normal after 7:00 pm. This figure is consistent with the SHA mobility report, the congestion begins if the TTI value is higher than 1.15 and the highest volume afternoon peak hours are 5-6 pm. In addition, it can be seen that both INRIX and Bluetooth TTI and PTI values are very similar to each other during the non-congested periods. The differences begin to increase as the congestion begins and reach the highest at 6:00pm then gradually go back to being equal. The reason for the differences during the peak hour is that HOV regulations are in effect along I-270 and the studied segment is entirely covered by one HOV lane. The northbound HOV lane operates during the afternoon peak hours from 3:30 p.m. to 6:30 p.m. As one of the benefits of HOV lane is to save travel time, travel time between HOV lane and general purpose lanes should be different. INRIX only provides one value for each time point and does not specify traffic information for HOV lane. Bluetooth detectors track individual vehicle travel times. Although all individual measurements are aggregated to provide a single number travel time, unlike INRIX they can reveal underlying travel time patterns resulting from non-homogenous lane operations.
Figure 4 shows a sample plot consisting of Bluetooth travel time observations, average Bluetooth travel times and INRIX travel time on Wednesday May 16th, 2012 in the study area, which is a typical weekday. As the graph shows, two separate travel time patterns emerge during the HOV hours (3:30-6:30 pm) presented by individual Bluetooth observations. Since there is only one HOV lane, aggregate Bluetooth travel time is close to the travel time of general purpose lanes. However during the last hour of HOV operations, INRIX data is biased toward HOV travel times that create high difference (as high as 20 minutes) between the two sources. So if Bluetooth is selected as data source, the impact of HOV lanes on reliability measures can be calculated by separating the trends using pattern recognition algorithms. This is not possible using INRIX.

**CONCLUSIONS**

This study investigated the impact of data source on travel time reliability measures by utilizing two independent sources: Bluetooth and INRIX to derive different performance measures. By using the paired-t statistical method, each performance measure is derived in pairs based on Bluetooth and INRIX data. The test results indicate that the reliability performance measures derived from the Bluetooth and INRIX data are significantly different from each other, when fifteen minutes time intervals are considered. By increasing the time interval, the difference of some measures (the Mean, Skewness Statistics, 85th and 80th Percentile Travel Time measures) become less significant. In addition, based on this empirical study, measures like Standard Deviation, Percent Variation, Width Statistics, Buffer Index, and Misery Index are more sensitive to the data sources compared with measures like the Mean, Skewness Statistics, PTI, 95th, 90th, 85th and 80th Percentile Travel Time Measures. Therefore, the measures that are less sensitive to the data source are desirable for performance evaluation purposes. Another finding of this study is that as travel time on HOV and general purpose lanes are different, it is necessary to develop separate performance measures for HOV and general purpose lanes. As INRIX does not differentiate between lanes, calculating the effect of HOV operations on reliability index is only possible through Bluetooth data. However pattern recognition algorithms are needed to separate the travel time patterns between the HOV and general purpose lanes.
REFERENCE


MANAGED LANES OPERATIONS AND SIMULATION USING CORSIM

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ABSTRACT
In a typical setting, lanes on a given freeway are designated either as regular or managed toll lanes. The former has no toll while the latter can only be accessed by paying a toll. If high-occupancy vehicles (HOV) do not need to pay, the facility is widely known as a high-occupancy/toll (HOT) facility. Some of the HOT lane facilities currently implemented in the U.S. are single-segment (SR-91 in California), while others are multi-segment (I-15 in Utah and I-10 in Texas). A single-segment HOT facility has essentially one entrance, one exit, and one tolling point. In contrast, a multi-segment HOT facility has multiple ingress and egress points that are located distantly from each other, and multiple tolling points. This paper focuses on the operations of HOV and HOT lanes. It covers several components of managed lane operations such as pricing strategies, lane choice models, and toll structures.

INTRODUCTION
In many countries, including the United States (U.S.), toll roads, with fixed toll rates that every traveler has to pay, date back at least to the late eighteenth century. At that time, the purpose of tolling was to recover the construction cost or to gain revenue. In the early 1920s, economists and transportation researchers started to consider tolling as a measure to manage traffic demand and reduce congestion that had started to increase in many places (1).

Congestion pricing, or value pricing, is a tool for mitigating traffic congestion because it has been observed that people tend to make more socially efficient choices when they face the cost of their actions and the social benefits (2). Congestion pricing usually leads rush-hour travelers to shift to off-peak periods or to other transportation modes. Removing even a small percentage of the peak-period volume from a congested facility through value pricing allows the system to perform much better (3). Congestion pricing involves setting tolls depending on real-time traffic conditions. This implies that tolls must vary according to time, location, vehicle type, occupancy of the vehicle, and current circumstances, such as bad weather, accidents, and special events.

PRICING STRATEGIES
There are several models that have been developed over the years to determine dynamic pricing strategies for managed lanes such as bottleneck, network, and self-learning control models.

The bottleneck model was introduced by Vickrey (4) and further developed by Arnott et al. (5). It focuses on the time at which motorists want to depart. Motorists in this model travel along a single road with a bottleneck or bottlenecks downstream of certain flow capacity. Over the years, many studies, have considered elastic demand, heterogeneous individuals, stochastic capacity and demand, simple networks, and alternative congestion treatments, to improve the simple bottleneck model.

Responsive Pricing
Responsive pricing is an approach to determine toll values based on the current HOT lane conditions. This approach is intended to manage traffic demand and maintain free-flow conditions on HOT lanes. Tolls are determined by the traffic density currently detected on the HOT lanes, the change in density from the previous interval, and
the level of service (LOS) at which the facility currently operates. When an increase or decrease in the detected density occurs, the toll is adjusted upward or downward accordingly. The magnitude of adjustment is based on a “look-up” table called a Delta Settings Table (DST) (8).

Closed-loop-control-based Pricing Algorithm
The closed-loop-control-based algorithm is another method for adjusting the toll based on real-time traffic measurements. The toll for each subsequent time interval depends on the toll at the current interval, current traffic density (TD), and the critical or desired density (D_cr). The procedure for determining the toll is as follows:

- Step 1: Calculate average traffic density of the HOT lanes, denoted as TD (t).
- Step 2: Calculate the toll for the next time interval, R(t+1), based on the following equation:
  \[ R(t+1) = R(t) + K \times (TD (t) - D_cr) \]
  where R(t) is the current toll; K is a regulator parameter defined by a user. K is used to adjust the disturbance of the closed-loop control, i.e., the effect of the impact between the measured traffic density and the critical density on the toll; and D_cr is the critical or desired density defined by a user.
- Step 3: Compare R(t+1) with the minimum and maximum toll thresholds defined by the user. If R(t+1) is less than the minimum threshold or greater than the maximum one, it is set to the minimum or maximum threshold value.

Time-of-day Pricing Scheme
Time-of-day pricing is the third pricing scheme in CORSIM. In this case, the toll is not determined based on real-time traffic conditions. Instead, it follows a toll schedule predetermined by a user. This scheme is useful for freeway facilities that have stable traffic demand pattern, e.g., during weekdays. In the CORSIM implementation of time-of-day pricing, multiple tolling periods (having different tolls and durations) can be simulated. The number of tolling periods can be up to 24; and the duration of each tolling period varies from 3 to 60 minutes, with a toll ranging from $0.00 to $12.00. These values were selected based on the current practice where tolls are set based on the time-of-day pricing scheme. The toll on SR-91 in California changes every hour and its highest value is $10.05.

LANE-CHOICE MODELS
In the areas where HOT lanes exist, motorists have the choice of traveling on either the HOT or the general purpose (GP) lanes. Choosing the HOT lanes means that they have to carpool or pay a toll, but at the same time they will save some travel time and their trip will be more reliable. Sometimes the choice between HOT and GP lanes is referred to as a route choice because HOT lanes are basically an alternative parallel route to the GP lanes with different cost and travel time. Knowing how many vehicles will choose to travel on the HOT lanes in the presence of a specific toll and the factors that affect drivers’ choice is very important for effective HOT lane operation. Empirical studies (9-12) showed that motorists’ lane choice depends on many factors such as travel time savings, toll amount, travel time reliability, trip purpose, and travelers’ characteristics. The lane-choice model within CORSIM is simulated endogenously and it is essentially based on a simple decision rule: motorists will pay to use HOT lanes if the benefit they perceive from travel time saving (TTS) is greater than the toll they are charged. The perceived benefit is the traveler’s value of time (VOT) multiplied by the perceived TTS, which is assumed to follow a truncated normal distribution whose mean is the real (actual) TTS (RTTS), and a standard deviation that can be customized by a CORSIM user. RTTS is the difference between travel times on GP and HOT lanes, averaged across a user-specified time interval and calculated internally by the software. Figure 1 illustrates the lane choice procedure for a particular vehicle, say j, approaching the warning sign upstream from an HOT lane entrance.

Figure 1: Drivers’ Lane Choice Module in CORSIM
In transportation studies and economics, VOT is the cost travelers are willing to pay to save time or the amount of money they would accept for lost time; it is usually expressed in dollars per hour. Travelers’ travel choices are highly affected by their VOT. There are several studies that estimate travelers’ VOT and examine the factors that influence it. It should be mentioned that VOT can be different among roadway users and vehicle groups; SOV, HOV and commercial vehicles. Previous studies (13-15) suggested that the average VOT of an individual is about 50% of his or her wage rate while others (16, 17) pointed out that the VOT can be as high as 120% of the wage rate, depending on the length and type of travel. Moreover, Outwater and Kitchen (18) suggested that the VOT of a vehicle representative increases as the vehicle occupancy increases. The increase of VOT between HOV 2 and 3+ can range from 3.8% to 39.7%.

**TOLL STRUCTURES**

Some of the HOT lane facilities currently implemented in the U.S. are single-segment, while others are multi-segment. Essentially, a single-segment HOT lane facility has one main ingress, one main egress, and includes one tolling point. Therefore, motorists who enter the facility during the same tolling interval pay the same toll amount. On the other hand, a multi-segment HOT lane facility consists of multiple entrances and exits that are located relatively far from each other. Downstream of every entrance there usually is a toll gantry and motorists will pay different tolls depending on where they entered and how far they traveled on the HOT lane facility. The exact toll amount a motorist has to pay when traveling on a multi-segment HOT lane depends on the toll structure implemented.

**Zone-based tolling**

In this approach, a HOT lane facility is divided into multiple zones. Whenever a motorist enters a new zone, he or she pays a specific toll. Consequently, the toll amount that a motorist pays depends on the numbers of zones he or she has traversed. Each zone can include multiple HOT lane entrances and exits. The toll at all the entrances that belong to the same zone is the same, however. The zone-based toll structure has been implemented on the I-15 Express lanes in Salt Lake City, the I-10 HOT lane corridor in Houston and the MnPass I-394 HOT lanes in Minneapolis.

**Origin-specific tolling**

In origin-specific tolling, the toll a motorist will pay depends only on where he or she enters the facility. Regardless of how far the motorist travels, he or she pays the toll displayed at the entry point. This can be unfair to the drivers who travel short distances on the HOT lanes. On the other hand, travelers can choose just once whether or not to use the HOT lanes and know in advance exactly how much they are going to be charged. This toll structure has been implemented in SR-167 in Washington State.

**OD-based tolling**

OD-based tolling implies that the toll rate a motorist will pay depends on where he or she enters and leaves the facility so there is a different price for motorists who travel through different OD pairs. The toll per mile can be different for different OD pairs, thus creating some equality issues among drivers. The tolls displayed before each toll gantry show the price to major destinations, but do not indicate the exact amount a driver will finally pay. This toll structure is implemented on I-15 in San Diego.

**Distance-based tolling**

In this toll structure, the toll charge that a motorist will pay depends on the distance he or she travels on the HOT lanes. The rate, that is, toll per mile, is the same for all entry locations at a specific time interval. At each entrance, the toll per mile is displayed. Such a toll structure has been recently implemented on I-85 HOT lanes in Georgia.

**Summary**

Table 1 summarizes the characteristics and toll structures of the multi-segment HOT facilities in the U.S.

<table>
<thead>
<tr>
<th>Facility</th>
<th>Length</th>
<th>Access points</th>
<th>Tolling points</th>
<th>GP/HOT separation</th>
<th>Toll structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-15 Salt Lake City, Utah</td>
<td>38 miles</td>
<td>18 points, 2 entrances, and exits at each direction</td>
<td>4 — one at the end of each zone</td>
<td>Double white line</td>
<td>Zone-based: dynamic pricing</td>
</tr>
<tr>
<td>I-10 Houston, Texas</td>
<td>13 miles</td>
<td>5 entrances and 3 exits WB and 5 exits EB</td>
<td>3 — one at the end of each zone</td>
<td>Flexible “candlestick” barriers</td>
<td>Zone-based: time of day pricing</td>
</tr>
<tr>
<td>I-394 Minneapolis, Minnesota</td>
<td>11 miles</td>
<td>5 EB and 5 WB</td>
<td>Double white line</td>
<td>Zone-based: dynamic pricing</td>
<td></td>
</tr>
<tr>
<td>SR-167 Renton &amp; Auburn, Washington</td>
<td>10 miles</td>
<td>6 entrances and 4 exits NB and 4 entrances and exits SB</td>
<td>Double white line</td>
<td>Origin-specific: dynamic pricing</td>
<td></td>
</tr>
<tr>
<td>I-15 San Diego, California</td>
<td>8 miles</td>
<td>9 entrances and 8 exits SB, 9 entrance and SB</td>
<td>8 SB and 9 SB</td>
<td>Concrete barriers</td>
<td>OD-based: dynamic pricing</td>
</tr>
<tr>
<td>I-85 Atlanta, Georgia</td>
<td>16 miles</td>
<td>5 entrances and 4 exits NB and 4 entrances and 4 exits SB</td>
<td>6 NB and 4 SB</td>
<td>Distance-based: dynamic pricing</td>
<td></td>
</tr>
</tbody>
</table>

1 Access points are the points where drivers can either enter or exit the HOT lanes.
2 Information provided by the I-15 Express Lanes Customer Service Center.

All four toll structures are fully implemented in CORSIM.
**SIMULATING 95 EXPRESS IN CORSIM**

95 Express will be deployed in two phases. Phase 1 has been completed and is in operation. It includes express lanes between SR-836/I-395 and Miami Gardens Drive/NW 186th Street in Dade County. Phase 2 will expand the express lanes northward to Broward Boulevard in Broward County. The future 95 Express includes express lanes constructed during both Phase 1 and Phase 2. Figure 2 is a map of Phase 1 95 Express and the future, completed, 95 Express. Phase 1 95 Express is being managed as a single-segment facility, while the future 95 Express is slated to be a multi-segment facility. More specifically, the future 95 Express will have five entrances and four exits southbound, four entrances and five exits northbound, and three tolling points in each direction. Some of these entrances and exits will be located very close to each other, while others will be at distances of approximately 10 miles. This implies that setting one toll amount may not be effective in managing traffic demand, and may not be fair to all users. Therefore, the future 95 Express may better be managed as a multi-segment facility.

**Figure 2: Map of the Phase 1 and Future 95 Express; A) Phase 1 95 Express, B) Future 95 Express; right are the entrances and exits of the Future 95 Express northbound direction. (Source: [http://www.95express.com/home/entryexit.shtm](http://www.95express.com/home/entryexit.shtm)**

**Simulating the Current 95 Express**

The northbound direction of Phase 1 95 Express was simulated to demonstrate CORSIM’s ability to simulate managed lanes. Simulation data were obtained from the STEWARD database every fifteen minutes between May 10 and 12, 2011 (Tuesday, Wednesday, and Thursday). On those days, the data from most detectors were available and there were no special events. Based on the 95 Express Monthly Operations Report of May 2011 (25), the peak period was 4:00-7:00pm for the northbound direction. Thus we calibrated our model against this time period and an additional thirty minutes were used for initialization.

Table 2 compares the reported performance statistics of the northbound direction of the 95 Express (19) with the simulated performance statistics obtained from the simulation.

<table>
<thead>
<tr>
<th>Tolls</th>
<th>Simulation model</th>
<th>Reported (May 2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>$0.25 - $5.75</td>
<td>$0.00 - $5.50</td>
</tr>
<tr>
<td>Avg. peak period</td>
<td>$2.17</td>
<td>$2.12</td>
</tr>
<tr>
<td>Avg speed (mph)</td>
<td>HOT GP</td>
<td>HOT GP</td>
</tr>
<tr>
<td>HOT Lanes operated above 45 mph</td>
<td>99.6%</td>
<td>99.7%</td>
</tr>
</tbody>
</table>

**Simulating the Future 95 Express**

The northbound direction of the future 95 Express was simulated to demonstrate CORSIM’s ability to simulate multi-segment toll structures. Similarly, the data used for simulation and calibration were obtained from the STEWARD database every fifteen minutes for three weekdays, May 10-12, 2011, for all detectors along the future 95 Express corridor.

The results presented in the following sections should not be used to compare toll structures and draw a conclusion on which particular toll structure outperforms the other. This is because the toll rates are not optimized against each structure, and the results could differ with the type and design of each HOT lane facility.

**Zone-based Toll Structure**

I1-O1 represents Zone 1, which extends from SR-836/I-395 to the Golden Glades Interchange, I2-O2 represents Zone 2, which starts north of the Golden Glades Interchange and ends at Griffin Road, and I3-O4 is Zone 3, which extends from Ives Dairy Road to the end of the facility at Broward Boulevard. In Table 4 (A) the facility performance measures under zone-based tolling are presented. Results indicate that the facility can be effectively managed using a zone-based toll structure.

**Origin-specific Toll Structure**

Table 4 (B) presents the results of origin-specific tolling on the future 95 Express. The HOT lanes can be effectively managed with this type of charging, but there may be some inequality issues among the motorists. A motorist who is traveling from I1 to O1, a 7.3 mile stretch, will pay the same amount of toll as someone who is traveling through the entire facility, I1-O4, which is about 21.0 miles long. This implies that the driver who travels from I1 to O1 will pay a toll rate of $0.42/mile while the driver who travels from I1 to O4 will pay a rate of $0.15/mile.
**OD-based Toll Structure**

In an OD-based structure, the tolls are calculated for each different OD pair. The results for this structure are given in Table 4 (C). As stated earlier, the responsive tolling algorithm was applied when testing all toll structures. However, ideally, a more sophisticated tolling algorithm should be developed to charge users based on their origins and destinations. This would help to maintain desired traffic conditions on the express lanes and fully utilize express lanes’ available capacity, without creating excessive inequality among different OD pairs.

**Distance-based Toll Structure**

In the distance-based structure, a toll rate for the entire HOT lane facility is set. Drivers are charged that rate multiplied by the number of miles they have traveled on the facility. This should result in less equity concern, but the structure might fail to maintain desired traffic conditions on the HOT lanes. Table 4 (D) shows the results when distance-based tolling is applied to the future 95 Express.

**SUMMARY AND CONCLUSIONS**

This paper summarized the main operating components of managed lanes and demonstrated managed lanes simulation using CORSIM by simulating Phase 1 and future 95 Express in South Florida. The former shows the ability to replicate the operations of a single-segment HOT lane facility, while the latter highlights simulation of different toll structures for multi-segment HOT lanes. The experiments showed that the CORSIM appears to capture the primary characteristics of HOT lane operations and management.

### Table 3: Value of time ($/hr)

<table>
<thead>
<tr>
<th>percent vehicles</th>
<th>VOT</th>
<th>percent vehicles</th>
<th>VOT</th>
<th>percent vehicles</th>
<th>VOT</th>
<th>percent vehicles</th>
<th>VOT</th>
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</thead>
<tbody>
<tr>
<td>Cars</td>
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<td>HOV 3+ not</td>
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<td>12</td>
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<td>10</td>
<td>15</td>
<td>50</td>
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<td>10</td>
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</table>

### Table 4: Performance measures of Future 95 Express

<table>
<thead>
<tr>
<th></th>
<th>I1-O1</th>
<th>I1-O2</th>
<th>I1-O3</th>
<th>I1-O4/facility</th>
<th>I2-O2</th>
<th>I2-O3</th>
<th>I2-O4</th>
<th>I3-O3</th>
<th>I3-O4</th>
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</thead>
<tbody>
<tr>
<td><strong>(A) Zone-based tolling</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Toll range ($)</td>
<td>0.25-2.75</td>
<td>0.50-3.00</td>
<td>0.75-3.25</td>
<td>0.75-3.25</td>
<td>0.25-0.75</td>
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<td>Avg. peak Period toll</td>
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<td>$1.66</td>
<td>$1.93</td>
<td>$1.93</td>
<td>$0.25</td>
<td>$0.52</td>
<td>$0.52</td>
<td>$0.27</td>
<td>$0.27</td>
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<tr>
<td>Avg speed (mph)</td>
<td>56.1</td>
<td>40.1</td>
<td>56.9</td>
<td>43.0</td>
<td>60.6</td>
<td>52.3</td>
<td>61.1</td>
<td>54.1</td>
<td>60.0</td>
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<tr>
<td>HOT lanes operated &gt;45mph</td>
<td>99.9%</td>
<td>99.9%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
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<tr>
<td><strong>(B) Origin-based tolling</strong></td>
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<td></td>
</tr>
<tr>
<td>Toll range ($)</td>
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<td>1.00-6.25</td>
<td>1.00-6.25</td>
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<td>Avg. peak Period toll</td>
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<td>$3.13</td>
<td>$3.13</td>
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<td>Avg speed (mph)</td>
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<td>56.9</td>
<td>45.0</td>
<td>56.8</td>
<td>41.8</td>
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<td>99.8%</td>
<td>99.9%</td>
<td>99.9%</td>
<td>99.9%</td>
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<td>99.8%</td>
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REFERENCES
ACTIVE TRAFFIC MANAGEMENT WITH CONGESTION MITIGATION TOOLS IN JAPAN

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ABSTRACT
Active Traffic Management (ATM) was introduced with leading edge technology that is well structured to manage traffic flow, reduce congestion and secure safety. Through control centers information such as accidents, congestion, weather, road defects, obstructions and lane closures are collected in real time. This information is then processed and delivered using a wide range of mediums.

Variable message signs (VMS) have been introduced to alert users to evolving roadway conditions. Proactive congestion prediction and real time information are used to encourage drivers to alter routes based on time reductions. Congestion prediction provides a time basis so that drivers can obtain travel time to their destinations and showed a 5% of traffic congestion reduction using road pricing, the giveaway campaign, and a guidebook notifying of peak periods. In addition well trained traffic squads for expressway patrol play an essential role.

OVERVIEW
NEXCO-Central operates approximately 2,000 km of expressways with Japan’s heaviest traffic volume roadway connecting three major Japanese metropolitan regions that together produce more than 50% of Japan’s gross domestic product. In order to operate these expressways safely and reliably while providing a high quality service and ensure the vitality of Japan’s economy, leading-edge construction, operations and maintenance technologies are essential under severe regional conditions of central Japan such as the diverse climate and geography, dense population and high traffic volume. Due to these unique regional conditions, continuous efforts have been made in traffic management field not only to offer safety to drivers but also to alleviate traffic congestion.

ATM’S PURPOSE
There have been three primary purposes in introducing ATM. First is providing accurate information to every single driver, second is encouraging drivers to use expressways wisely by offering choice of alternative routes and third is leading positive social effects such as declining accidents, alleviating congestion, reducing carbon emissions, and improving customer satisfaction. To reach these objectives, we have made use of ATM with the leading edge technology that is well structured to actively manage traffic flow and then carry out all the process automatically, reduce congestion and secure safety. Through traffic control centers, on-site firsthand information such as traffic accidents, congestions, weather conditions, road defects, fallen objects, and lane closures are collected real time. Information is appropriately processed and effectively delivered through wide range of mediums such as variable message signs (VMS), mobile VMS, advisory radio. ATM has effectively developed a variety of congestion mitigation tools making use of this information.

TRAFFIC CONTROL CENTER
Traffic control centers located in four regional areas operate approximately 500 km play a key role in making ATM work effectively. In close conjunction with the maintenance
and customer service centers the functions of the traffic control center include monitoring all road conditions and equipment operation, dealing with the incidents immediately, and providing real time expressway related information, and as a result minimizing the negative effects on traffic and recovering the expressway to the ordinary condition quickly. It also coordinates with the Expressway Traffic Police Unit, fire department, and other support agencies and functions around the clock to ensure that expressways are safe and reliable by dispatching tow truck, maintenance teams, ambulances and fire trucks. To minimize the negative effects such as secondary accidents and further expansion of traffic congestion and then recover expressways as soon as possible, the traffic control centers’ systems feature automatic and prompt information dissemination. Figure 1 illustrates the road information flow centered on the traffic control center. Although mobile devices are a popular way to obtain and disseminate incident information, from the viewpoint of higher reliability and accuracy of information, utilizing the traffic control center is more indispensable. Considering the importance of traffic control centers for securing smooth traffic and safety there is a recovery system in case of emergency. Meaning that if one of the centers breaks down due to earthquake and inclement weather another traffic control center complements the disabled center.

**CONGESTION MITIGATION TOOLS**

*Increase In Traffic Capacity*

Mitigation tools aimed to increase traffic volume consist of two types, hardware and software. As for a hardware type of changing road length and structures, four mitigation tools including the network expansion, ETC installation, road widening, and use of the roadway shoulders have been implemented. As for a software type of deploying equipment on expressways, VMS for alerting reduced speed have been used at uphill, sag or nonrecurring congestion point. Especially in urban areas with limited right of way, the hardware type with which road length and structures have to be changed according to the design could be difficult to introduce. Therefore the needs in the software type such as VMS for road operators operating urban or narrow areas are expected to increase. Figure 3 shows congestion mitigation tools for increase in traffic capacity.

**TRAFFIC CONGESTION IN JAPAN**

In order to build suitable congestion mitigation tools, causes of congestion need to be identified in advance. The causes of congestion in Japanese expressways are described in Figure 2. 60% of causes occur at uphill and sag locations with 18% at tunnel entrances and 13% at merging sections. The ratio of bottleneck in Japan occupies 90% of causes, meaning that most of congestions are caused by bottleneck. To solve this problem two types of congestion mitigation tools have primarily been used; the increase in traffic capacity and the distribution of traffic demands.
on the Tomei Expressway has provided for unexpected results. Originally, this traffic volume was the largest among the four lane expressway and the congestion was constantly observed during rush hours. After the shoulder use was conducted, congestion was reduced by 94% and the number of accidents was reduced by 30%. Moreover, since the shoulder has become narrowed from 3.0 m to 0.75 m after operation, the traffic safety measures were simultaneously applied to this section such as limiting the driving speed and installing the emergency parking space.

Figure 4: Example of temporary shoulder use and its effect

Variable Message Sign (VMS)

Noting an example of a bottleneck notification using VMS at a tunnel, the purpose is to alert speed reduction caused by distracted driving and to encourage quick restoration of driving speed. Displays of VMS show messages of “Congestion End 1 or 2 km Ahead” at 1 km and 2 km before the end of congestion, followed by blinking messages of “Congestion Ends at Tunnel Exit” and “Restore Speed” at the tunnel entrance. Messages of “Congestion Ends” and “Restore Speed” are displayed at the end of congestion again to remind the drivers. These displays help drivers realize the accurate location of the congestion end. By applying this method, the annual traffic congestion volume (km/h) has been reduced by up to 5%.

Although both fixed and mobile VMS have been used, an addition feature is the mobile VMS. When we are not able to place the fixed sign or nonrecurring congestions are found, this mobile VMS will be temporarily applied at any point. The VMS is a helpful tool for any road operator to take an action for congestion mitigation tools.

Distribution Of Traffic Demand

Another tool aimed to distribute traffic demand is dependent upon software. This software type is classified into three mitigation tools including the proactive congestion prediction, the real time information provision and the reduction in traffic regulation. By using these three tools selected according to each cause of congestion, it is expected to encourage drivers to change their choices of travel time and route.

Proactive Congestion Prediction

As a proactive congestion prediction, where congestion prediction is provided on a time zone basis so that drivers can easily learn the rough travel time to their destinations, road pricing that changes the toll by peak time and off peak time, the giveaway campaign, meaning that drivers passing during expected off peaks times are offered giveaway and the issue of a special guidebook at a peak period during a holiday season with predicted congestion information calculated based on the past data. The drivers are able to use this information to avoid the rush hours. With these approaches, there has been a successful reduction of 5% congestion in certain sections.

Real time information provision

As for real time information provision, we employ a variety of VMS to change the traffic flow by notifying real time travel information to every driver thus making every driver avoid traffic congestion areas. One of the features is travel time signs, which adds general travel time into the travel time passing current events based on the traffic counter data or the past data can be displayed. Map-based graphic travel time signs have been adopted to achieve better user-friendliness especially for elderly people and enables drivers to select the most appropriate route, lead to the destinations in a short time and eventually balance the traffic volume. At present, the information provided by road operators are still more accurate, reliable, and efficient to control the traffic behavior than mobile applications.

Table 1 shows the locations and objectives by VMS types in Shin-Tomei Expressway, which was newly opened to traffic in 2012. The key thing is that all drivers are able to receive the information that enables them to select the most appropriate route and pay careful attention to incidents on the way whenever they need. Therefore, locations of VMS and contents of displays have to be determined so that the maximum effects can be produced.

Table 1: Location of VMS

<table>
<thead>
<tr>
<th>Items</th>
<th>Locations</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Time Sign</td>
<td>After the toll gate at all Interchanges (ICs)</td>
<td>To determine whether to use expressway</td>
</tr>
<tr>
<td></td>
<td></td>
<td>To pay careful attention to incidents on the way</td>
</tr>
<tr>
<td>Map-based Graphic Travel</td>
<td>Before all Junctions where drivers have a choice of routes to one destination</td>
<td>To determine which expressway to go</td>
</tr>
<tr>
<td>Time Sign</td>
<td></td>
<td>To pay careful attention to incidents on the way</td>
</tr>
<tr>
<td>VMS</td>
<td>Before entrance at all ICs</td>
<td>To determine whether to use expressway</td>
</tr>
<tr>
<td></td>
<td></td>
<td>To pay careful attention to incidents on the way</td>
</tr>
<tr>
<td>VMS for Wide-area Info</td>
<td>Before exit at the ICs with good alternate route</td>
<td>To determine whether to use expressway</td>
</tr>
<tr>
<td></td>
<td></td>
<td>To pay careful attention to incidents on the way</td>
</tr>
<tr>
<td>Mobile VMS</td>
<td>Before congestion area</td>
<td>To pay careful attention to congestion (Secondary accident prevention)</td>
</tr>
</tbody>
</table>
Other Information provision
A variety of information dissemination media provide every single driver with the traffic information. For example, Vehicle Information and Communication Systems (VICS) provide the graphical traffic information with the drivers through the car monitors. Highway advisory radio is broadcasted along expressways and provides information before interchanges. Traffic information is provided through both control center mobile application and information kiosks at rest areas. Furthermore, Japan Road Traffic Information Center collects the traffic information nationwide and provides them through radio, telephone and the internet updating them every five minutes.

Reduction in traffic regulation
Since regulating traffic flows on heavy traffic expressways can cause congestion, adoption of the intensive maintenance operation has been used to avoid traffic regulations, which control the movement of vehicles for safe traffic flow by restricting usable lanes and to reduce congestion. As a result of this operation on the Tomei Expressway during two weeks in 2013, the number of traffic regulations was reduced by 40% from approximately 3,400 to 2,100, and then the number of traffic congestion was reduced by 70% from approximately 1,400 to 450 by best estimates.

TRAFFIC SQUAD
In order to collect accurate road information promptly use of well trained traffic squads play an essential part in information collection along with other equipment. The traffic squads’ role is not only to collect road information, but also to control traffic flow and provide roadside assistance. The key role of traffic squads is to patrol on the expressway to deal with the incidents such as traffic accidents, disabled cars, falling obstacles as well as to check pavement and road equipment. When traffic congestion occurs due to incidents traffic squads notify the caution to drivers behind with an LED display mounted on a patrol car. Their role of keeping the expressway in a safe, secure and smooth condition is different from police officers, which enforce speed and illegal vehicles based on the law. When receiving a call from a driver in an accident, the nearest traffic squads is notified with dedicated digital radio and make an urgent request on rushing to the scene. They make an instant decision on required emergency vehicles and materials and then request them to the traffic control center. They immediately regulate the lanes to alleviate the negative effects on the traffic. Furthermore the squads guide the injured drivers and passengers into the safety area to avoid the secondary accident.

Another important role of the traffic squads is to pick up fallen obstacles on expressways. For example, the big toolbox and tires dropped from vehicles are extremely dangerous. Traffic squads run and pick up the obstacles before severe accidents occur. More than 24,000 fallen obstacles were annually removed under the direction of one traffic control center.

CONCLUSION
In the ATM the traffic control center with state of the art technology has been established and promptly and accurately collect and provide road information for all drivers. Using this information, a variety of congestion mitigation tools have been carefully considered and implemented. As a result of utilization of these tools at the congestion areas, these tools have brought the positive outcomes of reducing traffic congestion by increasing traffic capacity and distributing traffic demand. Traffic squads also play an important role in working ATM effectively by collecting on site information and securing smooth traffic.

ATM is a well organized program with a variety of technologies and resources helps road operators keep users safe, travel times reliable and comfortable expressways by collecting and offering accurate information of the incidents and congestion ahead to every driver and as a result leading the reduction on traffic congestions and smooth traffic.

REFERENCES
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