IRF EXAMINER: FALL 2014, ITS: Smart Cities

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For permission requests, write to the IRF at:
International Road Federation
Madison Place
500 Montgomery Street
Alexandria, VA 22314 USA
Tel: +1 703 535 1001
Fax: +1 703 535 1007
www.IRFnews.org

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PREVIOUS EDITIONS
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There is a growing global consensus regarding the significant benefits of intelligent transport systems deployments and their utilization to address major transportation congestion, safety, security and environmental challenges. However, many challenges continue to inhibit the successful deployment and sustainability of cost-effective, technically-sound, and locally-appropriate integrated ITS solutions by government agencies, including lack of sustained funding and market transparency.

With this third issue of the IRF Examiner, the International Road Federation confirms its role as the leading provider of applied knowledge in areas of vital importance for the global community of road professionals. This vision has been carried out year after year, culminating with the 17th IRF World Meeting & Exhibition which welcomed more than 2,000 delegates from 92 countries in Riyadh, Saudi Arabia. The wealth of knowledge accumulated during the World Meeting has been the driving force behind our decision to launch the IRF Examiner as a freely available resource for the industry.

H.E. Eng. Abdullah A. Al-Mogbel
IRF Chairman
Mayor of Riyadh, Kingdom of Saudi Arabia

The convenience and simplicity that location-aware applications combined with connected vehicles have brought us is astounding, even when compared to what was available just a few short years ago. With the arrival of these innovative services, managing the resulting volume of data effectively and making sense of it has become a leading objective across our industry.

There is significant value in the data generated by road users, and the International Road Federation has a prime role to play in shaping policies and standards related to their usage. IRF members include highway agencies, research institutes, engineering consultancies, asset managers and ITS vendors. They are present in over 100 countries in all regions of the world, adding a unique perspective to our work. As you read through the third volume of our quarterly journal devoted to sharing industry knowledge, I invite you to join us and directly support the IRF’s global mission of better roads for a better world.

C. Patrick Sankey
IRF President & CEO

By working with leading industry and government specialists through a Committee on ITS and two sub-Committees, dealing respectively with International Business & Systems Engineering and Education & Training, the IRF seeks to promote the development of a true global market in ITS equipment and services, through support for use of open standards, access to information, as well as increased government procurement transparency.

This issue of the IRF Examiner supports one of the Committee’s key goals, namely serving as a clearinghouse of worldwide best practices, processes, solutions and case studies that are appropriate for the needs of recipient countries and regions.

Bill Russell
Chairman, IRF Committee on ITS
CEO, Eberle Design
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BRT Infrastructure, Coming To A Street Near You!

Main Author:
Andre Frieslaar
HHO Africa Infrastructure Engineering
andre@hho.co.za

ABSTRACT

Municipal engineers are having to deal with a new reality of bringing Bus Rapid Transit (BRT) infrastructure into city streets. The challenge is to build infrastructure that meets the operational needs of the public transport operator, at a reasonable cost and with materials that will require minimal ongoing maintenance. BRT infrastructure comprises busways, stations, terminals, bus stops and bus depots. Currently, the overall infrastructure costs for BRT projects is approximately US $10 million per dedicated busway kilometer, so wise investment in this infrastructure is critically important. This paper introduces BRT and gives an explanation why it is the mode of choice for implementation. Thereafter, the various BRT infrastructure elements are discussed. After a brief description of the MyCiti Interim Service that was launched in May 2011, key lessons learned from the Phase 1A implementation of the MyCiti infrastructure have been presented.

WHAT IS BRT AND WHY IS IT BEING IMPLEMENTED

What is BRT?

Bus Rapid Transit is defined as a high quality bus-based transit system that delivers fast, comfortable, and cost effective urban mobility through the provision of segregated right of way infrastructure, rapid and frequent operations, and excellence in marketing and customer service (1).

Metro and regional rail systems operate on Right of Way (ROW) category A (fully segregated rights of way), BRT systems typically operate within busy arterial streets, sharing the at grade intersections with general traffic (ROW B). The interaction, and hence interference of general traffic and BRT traffic at intersections, results in BRT systems being semi-rapid. Conventional bus systems, where buses travel in mixed traffic are called ROW C.

BRT systems are characterised by being situated within the middle of urban arterials. They have dedicated infrastructure for the buses to run on and passengers board and alight these buses at stations within the roadway median.

Why is BRT Being Implemented?

South African cities are increasingly becoming congested by the high usage of the private car. Current conventional road based public transport systems are stuck in traffic and hence offer little incentive for modal switching. Lack of capital and operational investment in the rail system, has left these network on the brink of collapse. In short, both public and private transport systems are under threat, which in turn impact on the efficiency and productivity of our cities. Government policy advocates the promotion of public transport modes, the management of travel demand and the restriction of the growth of private car usage. The focus of investment lies in the promotion of cost effective public transport systems, particularly in the major metropolitan areas. BRT is increasingly recognized as amongst the most effective solutions to providing high quality public transport on a cost effective basis to urban areas, both in the developed and developing world (1). The roll out of BRT is currently being pursued in the twelve major cities in South Africa with primary funding from the national treasury.

DESCRIPTION OF BRT INFRASTRUCTURE ELEMENTS

Busways and Stations

Typically BRT systems can be broken down into two operating environments for their buses, namely trunk
and feeder environments (Figure 2). The trunk routes are routes where dedicated ROW is allocated to BRT vehicles, and the buses travel between terminals and use either stations or intermediate transfer stations along the trunk route. Feeder routes are routes which connect the outlying areas to a terminal, and feeder buses tend to operate in mixed traffic, with some bus priority.

Median located trunk route infrastructure is favoured over curbside infrastructure for a number of reasons. The majority of the reasons are to maximise customer convenience in terms of ease of transfer and comfort during transfer, particularly with the closed fare system environments required in the South African context. Additional reasons for choosing median infrastructure are that it is easier to segregate and enforce for BRT vehicle use only.

Trunk routes typically have dedicated lanes for buses in each direction, with additional passing lanes being provided on express service routes to allow skip stop services. Stations are approximately 800 metres spacing and are custom built to the system requirements in terms of number and height of platforms. Low capacity systems require single platform stations, whereas higher capacity systems may require multiple platforms to serve high passenger flows and multiple destinations. The stations are equipped with a kiosk, fare system gates/turnstiles and a weatherproof platform.

Universal Access and NMT Provision
Wheelchair access to all platforms has to be provided using ramps at stations and dropped curblines at intersections. With those with visual impairments, tactile blocks need to be provided at intersections, along the median islands leading up to the station entrances and within stations to guide people to bus door positions. Tactile signage has been developed for wayfinding infrastructure to assist the visually impaired finding the station buildings. For hearing disabilities, induction loops have been placed in specific areas of the station to assist with auditory messaging.

All passengers need to access the roadway median to gain access to stations. The safe crossing of the roadway is achieved by either placing the station at a signalised intersection, or placing it midblock between two adjacent signalised intersections, where pedestrian signals can be provided. Where the roadway volumes and speeds are high and pedestrian/vehicle conflicts are severe, a pedestrian overpass may need to be considered to separate the pedestrian traffic.

**FIGURE 2: Description of a Trunk Feeder BRT System (1)**

**Depots**
Depot areas serve an array of purposes including bus parking areas, re-fuelling facilities, vehicle washing and cleaning, maintenance and repair areas, administrative offices for operators, and employee facilities. A typical layout and overall dimensions of a small depot site is 100 vehicles. The maintenance building contains a body spray-painting area, numerous pit lanes, and flat floor areas for maintenance.

**LESSONS LEARNED FROM MYCITI INFRASTRUCTURE IMPLEMENTATION**
During May 2011, the City of Cape Town introduced the MyCiti Interim Service between the Cape Town CBD and the Table View suburb. The service includes a trunk service between Table View station and Cape Town’s Civic Centre station, with feeder services at either end of the trunk route. The Cape Town end of the route is served by a feeder route between the V&A Waterfront and Gardens Centre, stopping midway along the route at Civic Centre station. From the Table View terminal station, three feeder routes operate and serve Blouberg Sands, Parklands, Table View and Blouberstrand.

The trunk route incorporates 16 km of dedicated busways, made up of 5 km of separate alignment busways and 11 km of median buslanes inserted into an urban dual carriageway arterial. The trunk route has 13 trunk stations, two of which are the terminal stations namely Civic Centre and Table View. The trunk route passed through 15 signalised intersections which have been adapted to accommodate bus phases.
**Employ a Knowledgeable and Innovative Design Team**

BRT design and implementation is new to South Africa, and there is a learning curve for South African based engineers and design teams. The design team involved in the infrastructure design will need a good understanding of the BRT operations in order to ensure that the infrastructure meets the operational requirements. Therefore, when procuring a design team, great care should be taken to set the quality requirements of the team at high enough levels to ensure that a suitably qualified design team can be chosen. Key personnel must have recent and relevant experience, and if necessary this experience may have to be sourced internationally, if teams want to meet the quality thresholds.

The design team needs to be innovative, as BRT has not been implemented extensively in South Africa. In bringing this technology to South Africa, the design team has to be able to adapt and modify the overseas principles and implement designs that meet the South African standards in terms of Geometric Design Guidelines and the Road Traffic Signs Manual (SARTSM). As an example, the introduction of BRT lanes at signalised intersection required the use of the existing SARTSM, which had been developed without any thought that BRT would be implemented.

**Go on a Study Tour of a Working BRT System**

In order to fully grasp the BRT concept it is important to study existing operating BRT systems. It is important to speak to people who have been involved in developing working BRT systems, and to ride on the systems. In doing so, an understanding will be developed for how the bus lanes have been located in the roadway, what materials have been used, how these materials are accommodating the bus loads, what strategies work and which do not. When using the stations, it is important to note the type of architecture used, materials utilised, the weather protection, safety features and passenger space and circulation provided. Exterior to the station, it is important to notice how buses dock at stations, what damage has been caused to buses and stations due to inaccurate docking and docking mechanisms used. Terminal and transfer stations should be visited to understand multiple platform and staff facility requirements.

**Do Not Reinvent the Wheel**

There is already a wealth of knowledge on BRT systems as a number of these systems have been designed and implemented all around the world. The Institute of Transport and Development Policy (ITDP) is a non-government organisation that has a particular interest in promoting BRT as a low cost, yet cost effective method of providing sustainable low cost mobility in urban areas. They have developed an extensive guideline, the Bus rapid Transit Planning Guide, which provides guidance on most aspects of BRT implementation.

**Design With the Full System in Mind**

Due to the expansive nature of BRT networks, it is likely to be impossible for the City to build the entire system in one phase. It is important for the City to plan the entire integrated public transport network early in the BRT roll-out, as the full system requirement needs to be understood before Phase 1 is constructed. The Phase 1 may typically include the city centre's terminal station, which will have to be sized and possibly built in Phase 1 to ensure minimal construction disruption to Phase 1 and subsequent bus services.

**Employ a Regular Design Review Process**

BRT designs incorporate a wide range of design issues, including roadway layout and geometric design, services design, NMT circulation, traffic signals, universal access design, road safety, road signage and markings, urban design and landscaping. Therefore, there is a high level of design development that occurs throughout the design and implementation phases of a BRT project.

**Design With Minimal Maintenance in Mind**

Once a BRT system is operational, it needs to operate for many years without failure, as any disruption to the busways and stations will result in major disruptions to bus services and inconvenience to customers. Furthermore, Cities can do without adding significant maintenance costs to their already small and underfunded maintenance budgets.

A major cost component of BRT systems is the insertion of bus lanes into the roadway. These bus lanes need to be designed to accommodate loads heavier than the maximum axle loads permitted on public roads. Bus lanes can be constructed using concrete or asphalt, the initial upfront cost of using either is very similar although concrete or more specifically continuously reinforced concrete requires far less maintenance than asphalt pavements.

**Design for Flexibility**

A BRT system could take between 15 and 25 years for a city to fully develop. It is likely that technology will change over time resulting in amendments to the full system design. BRT operations on a particular corridor may change over time, as land use changes occur and passenger travel patterns change from what was originally anticipated.
Internationally there is a broader debate regarding the adoption of low floor buses for both trunk and feeder routes, providing the BRT operations team more flexibility with regards to route design i.e. able to run direct services and not be fixed to a trunk feeder system. Being aware of these opportunities and planning for these potential shifts will ensure that any BRT system is flexible to technology changes.

BRT systems operate with a variety of buses varying in length from 9 m to 12 m and 18 m articulated buses. In some high capacity systems, double articulated buses in excess of 22 m are being considered. In order to retain flexibility, BRT designers should anticipate and plan for the implications of increase capacity on BRT routes.

**Design for Minimal Enforcement in Mind**

The fundamental principle underlying the success of BRT systems is the exclusivity of the bus lanes to BRT operations, and the efficiency, reliability and speed these lanes offer. The illegal use of these lanes by general traffic will undermine the BRT operations and reduce BRT to conventional public transport, which provides no travel time advantage over the private car.

It is therefore very important to send out a strong message to the public that the bus lanes are for BRT buses only. The most effective way of communicating this is through the use of colourisation of the bus lanes, and in South Africa the trend is towards using red. The striking contrast that a red pavement has to a black pavement clearly communicates that the red lanes are special lanes for special vehicle use.

**Involve and Inform the Public**

The City should appoint a media liaison team to ensure that the public are made aware of all planned construction and potential disruption to normal traffic conditions. This team should react quickly to negative public comment on the system or during construction, to ensure that public perceptions of the system remain positive. The City should engage with potential objectors to the system.

Prior to the construction of any section of the works, residents directly affected by the works should be served with an information letter drop, where the works are described and the potential length of disruption of normal traffic operations detailed.

**Utilize the BRT Project to Improve the Urban Environment**

Traditionally roadways have been designed for the motor car, where numerous lanes are surfaced for car usage and in some cases minimum width sidewalks are installed to accommodate pedestrians. These environments tend to be harsh for the person on foot, or on a bicycle.

The insertion of a busway into a roadway is an opportunity to transform the entire roadway into a linear urban park. BRT passengers arrive on foot from all directions and need to be afforded safe passage to the roadway median to access the system. These station environments need to be attractive and accommodating in order to heighten the passenger experience of the system and ensure passenger satisfaction, safety and recurring patronage. The urban design of intersection areas and station precincts is therefore a key consideration and worthy of detailed planning and design.

**CONCLUSION**

BRT is the establishment of a transformed world class public transport service that is customer oriented and run on business principles. It is key to underpin the project with sound business, operation and transportation input, so that the outcomes maximise the benefit to the passenger, the customer, while providing a viable business model to the transport operators and associated service providers.

All municipalities that embark on a BRT system will gain a thorough understanding of the way these systems operate, before breaking ground on the first infrastructure project. This paper documents significant lessons learned through the infrastructure design phase of the MyCiti Phase 1A busway project. Taking note will greatly assist cities with their BRT roll out and ease the burden of what is a large and challenging, yet rewarding undertaking.

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New York City ITS Deployment and the Midtown In Motion

Main Authors:

Mohamad Talas
Deputy Director, Systems Engineering
New York City Department of Transportation
mtalas@dot.nyc.com

William R McShane
Chairman Emeritus
KLD Engineering
bmcshane@kldcompanies.com

ABSTRACT

New York City (NYC) has designed and implemented a master plan for modernization of the ITS infrastructure. NYC has installed over 10,000 traffic controllers and is projecting to complete all the City’s 12,500 signalized intersections. The NYC Wireless Network (NYCWiN) communications backbone uses ITS protocols and provides two way communications from the NYC Traffic Management Center (TMC) to monitoring and controllers devices. This deployment integrates all of NYC’s five borough and a solid-state controller characterizes the integrated system. NYCDOT completed an Active Traffic Management Project called Midtown In Motion (MIM). The objective was to capitalize on key programs and use existing infrastructure to deploy vehicle detector technology and send real time data over NYCWiN from the TMC. At TMC, an Advanced Central Adaptive system analyzes the detectors data of travel time, volume and queuing intensity provided from field deployment of 200 microwave sensors, 50 traffic cameras and E-Z Pass readers at over 100 intersections.

NYC ITS KEY DEPLOYMENT

In the last decade NYC Department of Transportation (DOT) have modernized the ITS backbone and major control deployment that established the foundation for advanced ITS applications. The following are strategic deployments in NYC:

- A solid-state controller designed to NYC requirements that depended strongly on NEMA and New York State Standards for all components and subassemblies as well as ITS protocols, but with the controller re-packaged to be more efficient for the typical NYC intersection. Further, by rigorous specification, procurement, and acceptance testing NYC has installed over 10,000 traffic controllers and projecting to complete all 12,500 signalized intersections upgrades by 2014.

- A NYCWiN wireless communications backbone that fully uses ITS protocols, and is capable of handling all sensing, controllers, and supervisory needs over the five counties, 400 square mile expanse, including all of Manhattan, one of the most intense urban infrastructures in the world; So far there are 9,000 intersections on NYCWiN.

- An extensive detection system that currently uses microwave sensors and video cameras, and is equipped to handle E-Z Pass transponders and newer developing data streams.

- Currently there are over 600 Microwave detectors and over 200 transponder E-Z Pass readers.

- A new TMC central computer operating environment (NYC_TCS) capable of central control and monitoring and controlling up to 12,600 signalized intersections.

Other Key Projects

NYCDOT ITS has a number of cutting edge components and has won awards nationally for its innovation. Smart Lights are one component of the ITS. Below is an overview of the ITS, showing the signal work being done to best respond to ebbs and flows in traffic, continuing work to ensure that vehicles and pedestrians move as safely and smoothly through the city as possible.
Traffic Signal Retiming Project

DOT has begun a citywide and corridor based, traffic signal retiming project to be completed by the end of 2011. This project includes most of Staten Island’s arterials roads. The goals of the retiming project include:

- Improving traffic flows and decreasing travel time along arterial roads. The retimed signals would move groups of vehicles as far as possible during one phase, while respecting both the directional flow and the capacity of the roads.
- Discouraging speeding to enhance safety, this can be done by adjusting the signals so they turn green along with the flow of traffic.
- Increasing pedestrian walk times, particularly across arterials. We can improve safety and reduce pedestrian fatalities and injuries by allowing a walking speed of three feet per second. This provides sufficient time for pedestrians — including children and seniors, our most vulnerable populations — to cross the street.

To date, the design work for retiming over 1000 intersections has been completed citywide and work continues to complete all the 1500 intersections in 2011.

Highway Intelligent Transportation System and Support for Construction Projects

ITS uses technology such as traffic cameras and electronic message boards to improve traffic flows and inform drivers. We are currently implementing a Highway ITS project on the Korean Veteran Parkway, the Belt Parkway and the FDR Drive and the East River Bridges. The deployment includes fiber and wireless communication to support video traffic cameras, variable message signs (VMS), RFID readers and travel time signs. Other highway projects is being developed in conjunction with the ITS work New York State DOT. The City now has up to 500 traffic cameras that are monitored from the TMC, JTMC, over 100 VMS signs and more than 1000 detectors technology. In addition to the capital improvement projects, all the major construction projects require mobile ITS deployment to support maintenance and protection of traffic plans and detour management. The city successfully accelerated construction projects by using ITS deployment to mitigate closures impact. This was implemented on all East River bridges construction projects, 2nd Ave subway and Lower Manhattan constriction projects.

Transit Signal Priority

Based on the upgrade of the traffic Control system the city has deployed transit signal priority function to support the BRT projects. Two pilots were completed on Victory Boulevard and Fordham Road by using optic technology to actuate the signals and extending green time for the busses. However DOT is working on utilizing NYCWIn wireless communication to deploy TSP on other foru major arterials.

Smart Lights (also known as Adaptive Control System)

In places where traffic flow is inconsistent and unpredictable, Smart Lights can be good option for improving traffic flow. We have implemented a Smart Light pilot project at the entrance to Staten Island College at Victory Blvd., where there are unpredictable traffic patterns due to student arrivals and departures. This smart light system is dependent on both the electronic signal controllers and the wireless communication system described above. Smart lights are programmed with an algorithm that monitors changes in traffic flow in real time and requests traffic signal pattern changes from the Central Traffic Control System at the TMC, which sends the pattern to the field almost immediately.

Smart Lights are best used when the existing daily traffic pattern is not predictable. When traffic and pedestrian demand are predicable, a pre-planned traffic signal pattern is most suitable since it minimizes abrupt changes in signal patterns, which can cause traffic backups and congestion and can interfere with pedestrian safety.

Since the Smart Light has been installed at the Staten Island College entrance at Victory Blvd., DOT has measured approximately 19% less westbound cars waiting to turn left into the college, and a 19% increase in the number of vehicles turning left into the college at the light per cycle. There is an average increase of 13% in the number of cars going through, eastbound on Victory Blvd, and an average of 11% more westbound through and right turning cars are able to go through the green light per cycle on Victory Blvd.

NYC Active Traffic Management and Midtown in Motion

New York City Department of Transportation’s (NYCDOT) and the Federal Highway Administration (FHWA) jointly announced the start of Midtown in Motion (MIM) in the summer of 2011. This paper is an overview of the system, the different ITS technologies deployed and their integration as part of the Active Traffic Management (ATM) system developed by NYCDOT.

The NYCDOT instituted the MIM project to promote multimodal mobility in the Midtown Core of Manhattan, a 110 square block area or zone from 2nd to 6th Avenues, 42nd to 57th Streets. Control extended from 86th
Street to 23rd Street, focused on the core zone. The MIM Project utilizes ATM and the full capabilities of the NYCDOT ITS infrastructure -- advanced solid-state traffic controllers, network of sensors (video, microwave, electronic toll collection readers), wireless communication system, and the New York City Traffic Control System software system that manages the project. The system architecture is shown in Figure 1. The signal-timing measures applied by MIM complement other efforts by the City to improve traffic operations and safety. These efforts include turn bays and split phase signals.

The active traffic management component of the MIM Project focuses on using the sensor network to (1) detect developing conditions, (2) present the information to the NYCDOT operator and (3) recommend signal plan changes to the operator.

MIM provides signal timing changes on two levels: Level 1 is strategic and implemented by avenue, to rebalance the traffic entering the zone by changing the signal plan on the avenue approach to the zone. Level 2 is more tactical, in that it is designed to address shorter-term fluctuations of “severity” of congestion on competing approaches (avenues and crosstown streets) at certain key intersections, and adjust the allocation of green time to alleviate a localized congestion problem that is developing.

Level 1 control, starts from a carefully designed pre-stored library of timing plans. These timing plans are designed offline and are relevant to arterials inside the Midtown study area. It is the combination of these timing plans that are made of strategies to be applied in real-time to a specified array or grid of intersections. As a result of applying these specially designed timing plans, traffic progression patterns are adjusted and serve the overall purpose of regulating traffic into the Midtown study area, thereby enhancing mobility inside the area.

The library of Level 1 timing plans are prepared offline based on NYCDOT archived traffic data (volume and occupancy) and the categorization of different reference patterns. Activation of a certain combination of timing plans (i.e., strategy) is triggered by real-time travel time data; in this implementation, ETC transponder readers are employed to provide high resolution individual-vehicle-trip based travel time data. Figure 2 presents a snapshot of the travel time in the system, in real time.

The active traffic management component of the MIM Project focuses on using the sensor network to (1) detect developing conditions, (2) present the information to the NYCDOT operator and (3) recommend signal plan changes to the operator.

Level 1 control of the system runs between 8AM to 8PM Monday through Friday and based on the real time traffic conditions alerts the operators in the NYCDOT TMC to changes in the travel time and vehicle speed and recommends signal timing adjustments. The operator then reviews video cameras and other sources of information in the vicinity of the flagged avenue to identify the cause for the change in travel time. The TMC supervisor then decides the appropriate course of action to handle the event, which could be signal timing adjustments or requesting that NYPD address the situation (e.g., disabled vehicle, illegally parked vehicles). Level 1 controls consist of four recommended signal timing plans that are based on the number of times vehicles must stop for a given roadway segment.

To evaluate the system performance a comparison of travel time by roadway segments was performed. Based on the testing to date, in general the average speed improved noticeably. The speeds in the approaches to
the zones reduced to some degree as expected. The speeds improved overall inside and outside the zone.

Level 2 control is a split adjustment and based on Severity Index (SI), which is related to an estimate of queue length (traffic congestion) by approach. The longer the queue, bigger the SI. The control algorithm attempts to reallocate green time between approaches to reduce queuing if possible and to achieve equity between the approaches. Under the current implementation, the splits are adjusted every three signal cycles.

Level 2 can reduce queuing while achieving equity during the period, where feasible. This will vary by intersection. Level 2 implementation suggests that there are intervals wherein the "splits" (time allocated for the green signal) can be adjusted to better service needs to either the avenue or crosstown street, which is part of the objectives of MIM.

The extensive sensor network is enabling a rich data archive to be built. Combined with the record of actions taken and experience gained, the active traffic management will move to the plateau of a learning traffic adaptive control environment, in which new plans can be developed based upon the data archive and the experience gained.

The extensive data now available due to the City's ITS sensor network, suitably analyzed and combined with operational experience and the wisdom it imparts, confirm a basic principle----significant variation in the zone is the norm, and while there are clear aggregate patterns, the daily fluctuations require active traffic management that anticipates that reality, and is designed for it.

To evaluate performance at the intersection level, three metrics were developed: The relative distribution of SI, which is the percent distribution of pairs of SI (avenue SI, crosstown street SI) over time for a given intersection. The higher the percent of lower SI pairs, the lesser the severe the congestion is; Average SI shows the average queuing condition over time for a given approach; and Equity Ratio shows how balanced the control was over time at an intersection between the competing approaches. Figure 3 presents the sort of results that are expected.

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**FIGURE 3: Level 2 Control Sample Results**

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<th>With Control</th>
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<td>Crosstown St Average SI</td>
<td>1.83</td>
<td>1.67</td>
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<tr>
<td>Equity Ratio</td>
<td>1.37</td>
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Light Rails Build the City: Constantine’s Light Rail as a Key Element of its Transformation Strategy

Main Author:
Jorge Bernabeu
IDOM
jbl@idom.com

Co-Authors:
Concepción Ortega
IDOM
cortega@idom.com

Sonia Bortal
IDOM
sbortal@idom.com

ABSTRACT
Algeria is undertaking a challenging program of light rail development in ten major cities. The case of Constantine’s light rail is especially significant. Light rail will transform both the transport and mobility network of the city, and its urban settings while reducing the traffic and population density in historical Constantine. By urbanizing the new part of the city, it will encourage people to move to these new areas. The extension of the first line contains two double track light rails: the first one (10.4 km and 11 stations) starts on Zouaghi multimodal station connecting with the new urban development of Ali Mendjeli Ali, the second line (2.7 km and 4 stations) connects Zouaghi station with the international terminals of Mohamed Boudiaf’s airport. Light rail becomes a key element on establishing an attractive strategy to transform the city: to recover urban values and to make Constantine a well-known international cultural reference.

THE CONSTANTINE LIGHT RAIL IN ALGERIA

Objectives of the Project
Considering the European experiences with public transport, but conscious of its own personal character, Algeria is undertaking a challenging program of light rail development in 10 major cities, among them: Algiers, Oran, Constantine, Sidi Bel Abbes and Ouargla. The case of Constantine is especially significant.

Constantine, one of the oldest cities in the world, is a major city in Mediterranean history. The third largest city of Algeria, anciently named Cirta, the capital of Numidia, has for the last 17 centuries the name of Emperor Constantine I, who rebuilt it in 313. Constantine is known as the “City of Bridges”, the “City of Eagles,” but also the “City of Malouf.” It’s a city of culture and tradition in a privileged natural place (1). Recently, it was designated the Capital of Arab Culture in 2015.

The Ministry of Transport, with the public entity Entreprise Métro d’Alger, develops the tram project in the city of Constantine aware of his transcendence as structuring element with capacity to transform the city, not only in the aspects of transport and mobility, but also the spirit of the region, introducing new dynamics to the future.

Looking to future, light rail public transport will link the cities of the Wilaya of Constantine (Constantine, Zouaghi, Ali Mendjeli and El Khroub), totaling one million people and will help to covert the historic city Constantine in an open-air museum and an international cultural reference.

Project Methodology
Through experience, we know that in order to realize this vision, we will need to develop a strategy for dealing with changes and uncertainties. We aim to show how our method to execute this project will itself, mean; growth, the expansion of the transport system, innovation, the development tools to be used, life quality, greater interaction using the attractive high design specification service and sustainability, conscious of the environment and the economy of the project. The methodology involves dividing the project into 5 phases, preliminary design and environmental analysis, avant project (design and specifications), procurement; works supervision,
commissioning and testing. These phases are further subdivided into sub-sections. The program of 5 phases covers the planning and preparation, optimizing of alignment and setting up of the requirements for the catenary system and the power supply. The process described will deal with the question of interfaces with all internal and external players or stakeholders involved.

**Phase 1 Preliminary Design and Environmental Impact Assessment (EIA)**

During this phase the premises set up for the infrastructure design. At the end of the phase, the sketch design (the result of previous studies) needs the approval of the Constantine's Wilaya and main stakeholders. The sketch design developed consider: demand estimate for each alternative, landscape and urban integration, architectural design and urban integration, stations, structures/bridges, tramway depot, energy, signaling, operation control centre and communications technology, reallocation of utilities, purchase of land, traffic and road area.

**Phase 2 Avant Project**

This phase includes the design and development of both the infrastructure and the transport system. The design is done according to local and international standards and norms but with all technical recommendations of safety, operation and maintenance.

**Relevant Issues Here Are:**

- Alignment and road design with all technical consideration of safety, tramway priority, urban integration, transport systems coordination, etc.
- Technical specifications for rolling stock
- Technical specifications for equipment (energy simulation, signalling coordination for priority for tram, SIV (System of Information for passengers), PCC (Control Centre and communication with Traffic Centre of Constantine city)
- Work plan and traffic simulation for partial works and provisionally deviation
- Track design including noise and vibration measure, special design for buses and tramway platform
- Urban design with the safety recommendations to distinguish pedestrian, cycles, tramway, car space
- Stations design with an study for itineraries to other transport systems or attraction points of the city
- Operation and maintenance plan

**Phase 3 Procurement**

The main activity in this phase is providing all necessary support required by the Entreprise Métro d'Alger to carry out the tender process. Support is given in the definition of the strategy to be used, the documentation to be generated, and the evaluation of the subsequent bids and the preparation of the contract.

**Phase 4 Construction**

Then the design must be validated. During this phase we review the project and design that the constructor prepare, checking that the key aspects of the project intentions are obeyed and indicating the relevant changes to be made, if necessary. The initial design reviewed will be followed up to include any modifications or changes. All supervisory and delivery controls are implemented, including the supervision and monitoring of environmental issues.

Interface management monitoring has high importance during all the works period in order to coordinate all technical disciplines.

**Phase 5 Commissioning**

This is the period for the assessment and all tests on the infrastructure, transport equipment and rolling stock, before operations start. The key issues dealt with in this phase are: the commissioning of the system with the collaboration of all the team, contractors and suppliers of the transportation system (including Rolling Stock), to guarantee the RAMS parameters for the whole system (global and individual), the carrying out of operation testing without passengers and the adjustment of traffic cros

**General Description**

A first section of the Constantine’s light rail has recently been achieved and will be opened to the public on the 4th of July 2013. With its double track, 11 stations and 8 km long line, it connects the centric Ben Abdelmalek stadium with Zouaghi neighborhood, lending on the south of the city on Constantine, and where a multimodal station is projected (Figure 1).

The extension project contains two double track light rails: the first one starts on Zouaghi station and connects with the new urban development of Ali Mendjeli Ali. It’s 10.4 km long and counts 11 stations, two overpasses, three railway underpasses, two double road underpasses, and one park and ride. The tram frequency of this section would be the same as the one used in the first section (about three to six minutes).

The second line is 2.7 km long and connects Zouaghi
multimodal station with the two international terminals of Mohamed Boudiaf’s airport. It counts with three stations and one overpass. The tram frequency on this section will be about 30 minutes, and should be adapted to the flight times of the two airport terminals.

The design of both extensions makes it possible to insert a by-pass in the connection point in Zouaghi, enabling a new operating scheme in which it will be possible to take a tram from Ali Mendjeli to the airport without changing the tram.

The project included a very important work of light rail insertion through the city and urban landscaping its surrounding areas in order to make it part of the city. In this sense, the design of every element of the project was inspired by the local traditions of Constantine, but with a prospect of modernity.

For example, the design of the shelter was particularly inspired by the shape of the catenary suspension bridges. Through its innovative structure, it is also an icon of modernity, unprecedented in international achievements tram, and provides a very consistent solution between its structural elements and constructive solution. Overall, it gives a formal, attractive, very recognizable presence of adequate scale taking into account the context of the extension.

The arcs and symbols of Constantine inspired the overpass of the light rail on the East-West highway. It was conceived as an iconic bridge, a door between Constantine and Ali Mendjeli and a prominent bridge from the highway, representing the dynamic future of the province tram and its citizens. Similarly, for the light rail, it means the symbolic output of the urban part of Constantine and its important historical past, to the new city of Ali Mendjeli, representing the present and future urban development. This double steel arc is covered with a holographic area changing color with angle of incidence of the light, like a permanent rainbow illuminating the landscape of Constantine.

### DIFFICULTIES AND EFFORTS

The first challenge of the project was to get used to the idiosyncrasy of the site, its administration, its organization and to understand the role of each involved member, such as the steering committee (comité de pilotage), architects, etc., in order to offer them the best interpretation of what they expect through this project. Other difficulties such as differences in the language, the used standards, the use of local money, the cost of living, the topography system used there (Lambert Nord Algérie) were also overpassed, and without harming the main project deadlines.

Technically, there were different delicate points along the light rail lines. The most important were

#### Zouaghi Exit

At this point match three tram lines: line 1, the extension to the airport and Ali Mendjeli. Also, this is one of the main access points to the city of Constantine, resulting in permanent congestion of cars and urban space that does not allow expansion. In this place, next faces a Zouaghi tram stop, authorities are conducting a multimodal station project still in design and had to be taken into account when designing tram extensions, in terms of layout in plan, to dimensions, the access roads to the multimodal station, etc. To all this is added the difficulty of the terrain of the site, which the tram line 1 has adapted Constantine, ending its stretch on an embankment over 5 meters height to the height of the adjacent road. The extensions of the tram line made by a viaduct has to take into account both the current and future scenario, considering the need to maintain tram in service during construction of the extensions, without affecting its service.

#### The Access to the City of Ali Mendjeli

This is the single point of access for the city that is living in permanent traffic congestion, especially at peak times. The insertion of tram level may only increase the problem, although the goal is to reduce the number of vehicles entering the city. The solution adopted has been to bury the access roads to the city, leaving the surface tram into the city and having this critical point of the main stops Mendjeli Ali and wide parking place for its users in order to change to tram and move more comfortably and quickly. Besides problems of congestion, the tight radius at the entrance, the police academy had to maintain a minimum distance of safety and the presence of a trough have been other challenges to be
overcome in this critical and important extension to Ali Mendjeli.

The Design of the Urban Intersections and Underpasses
Their insertion into the local environment with its difficult topography and their interference with the existing traffic, urban live, buried networks, etc.

Transformation of the City
• Among the global structuration of the big city of Constantine, there is a proposal to move part of Constantine’s citizens to the new city of Ali Mendjeli for a better quality of life (modern and new buildings, better urban furnishing, less jam and contamination, etc.) but without disconnecting them from their precious Constantine, encouraging them to leave their cars outside the city in order to take part in the new image of the historical city. In this sense, the light rail solution is probably, among the city network (cableway, light rail...) and beside bridges, the optimal transport solution to extend the limits of the city beyond its surrounding cliffs, reducing the already high traffic density in the few access points to the city.

• Much more than just an extension, the two new light rails extend their tracks in order to conquer new suburbs, defining the future development of the urban scheme in the remaining unconstructed land between Ali Mendjeli and Constantine. In fact, the track of the extension has been designed to allow the insertion of new stations in these peri-urban areas. With the demography evolution expected in Constantine, which includes Ali Mendjeli and improved quality of life. It’s just a matter of time before all this free land will be converted into new modern neighborhoods.

• The frequency of light rail is about three to six minutes, so that the trip will last no more than 24 minutes traveling from Ali Mendjeli to Zouaghi, the multimodal station of Constantine, and only 37 minutes to the Ben Abdelmalek station, the first station located in the city center of Constantine.

• Ali Mendjeli is going to be the third most important student city of Algeria. A huge student city with a capacity of 44.000 students is under construction, as well as a multidisciplinary university, which will receive young people from all over Algeria as well as other countries. The connection with the airport by light rail will be an attractive and cheap transportation solution for the residents.

• The new student city of Ali Mendjeli will provide a high level of job opportunities for people who live in historical Constantine, nearby El Khroub located east of Ali Mendjeli, or southeast of old Constantine, just in the continuation of the light rail extension Zouaghi - international airport, as shown in the Figure 2. This may be an additional extension of the Constantine’s light rail, forming a triangular closed network, which enables a large choice of moving scenarios in the metro Constantine area.

FIGURE 2: Global Exploitation Network Scheme in the Wilaya of Constantine

• The light rail solution will provide transportation commodity and city decongestion like may be other transportation solutions. It’s also an urban furnishing project which proposal is to insert the light rail into the citizen’s daily life, taking advantage of any left area around it to create rest and meeting points, leisure and sport areas, providing the city with life and color.

CONCLUSIONS
The tram is a dynamic element that contributes not only to establish new mobility schemes that favor public transport, but also a profound renewal of urbanization and the allocation of public spaces in cities.

Constantine’s case highlights the capacity for renewal and impulse that can make the tram. The project combines the respect to historical tradition of Constantine with the will to modernize the new urban developments. Light rail has become a key element on establishing an attractive strategy to transform the city: to recover urban Constantine values and to make an outdoor museum and a well-known international reference culture. The tram of the city is always for its citizens.

REFERENCE

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Analysis of Congestion Pricing Influence on Travellers’ Mode Choice in Tehran

Main Author:
Saeid Sherafatipour
PhD Student
Civil and Environmental Engineering Department
Tarbiat Modares University
sherafatipour@yahoo.com

Co-Authors:
Seyedehsan Seyedabrishami
Assistant Professor
Civil and Environmental Engineering Department
Tarbiat Modares University
seyedabrishami@modares.ac.ir

Mahmoud Saffarzadeh
Professor
Civil and Environmental Engineering Department
Tarbiat Modares University
m_saffar@modares.ac.ir

Zahra Vafaee
PhD Student
Management Department
Tehran University
vafaee.z@gmail.com

ABSTRACT
Traffic congestion is induced by unequal balance between demand and supply in transportation systems. While routes’ capacity is considered as limited and rare sources, travel demand has increased with the increase in population and overall welfare level. One of the most important strategies of travel demand management to cope with these problems is congestion pricing in urban network. The objective of this study is to analyze travellers’ attitude toward congestion pricing in central area of Tehran, Iran. The required information was gathered using stated preference (SP) questionnaires and through interview in destinations and the share of various modes has been calculated employing multinomial Logit (MNL) discrete choice model. The results show that half of travellers give up private vehicles by applying congestion pricing of 30,000 Rials (1), and then the share of public transportation will rise respectively. If pricing increased to 135,000 Rials, 95% of travellers change their mode from private vehicles.

INTRODUCTION
High congestion of the commercial and office users in some urban areas absorbs a large number of trips during the daytime which in turn leads to traffic congestion, abnormal travel time, and environmental pollutions in these areas. Hence, some strategies must be considered to prevent the waste in passengers’ time and costs. Assigning tolls for entering private vehicles to these areas is among the strategies, which provide reduction of congestion as well as an income source to develop public transportation systems. Congestion tolls can be implemented at different scales ranging from individual lanes to network levels (2). In this research, the effect of tolling on travellers’ behaviour is investigated to obtain ideal congestion in study area routes through design of various pricing scenarios.

There are various tolling approaches including toll circle or cordon, taking the toll based on travel length, as well as multi-circle systems to charge tolls in the congested area. Selection of the appropriate method is highly
controlled by the restricting objectives and pricing. Before applying congestion pricing programs, congestion was imposing a weekly $7 million to the business and various people in London, England. The initial goal of pricing program in the routes was to reduce traffic congestion, travel time and delay, create a financial resource to develop infrastructures of the transportation system, and improvement of life quality and status in central area of the city. In this city toll circle system was applied where the charged fee was equal for all vehicles entered to the program, irrespective to their travel length (3).

In general, charging the tolls for entering to the pricing area is based on varying charge and lack of charging for lowly congested hours. Among the positive consequences of pricing policies in this city, 20-25% route congestion reduction, the change in the number of vehicles entering to the pricing area, the change in buses’ set-off schedule because of an increase in average movement speed, the increase in share of using public transportation system, reduction in air pollution level, and an increase in the number of vehicles with clean fuel.

**METHODOLOGY**

The methods for evaluation of influence of congestion pricing on travellers’ mode choice behaviour are based on demand curve or are independent from them. Curve-based methods are, in turn, categorized into two classes: revealed preferences (RP) and stated preferences (SP). Through revealed preferences, it is tried to detect and measure people's choices in the real world when they make a decision. To rate an un-priced service, in this approach the observed behaviour of people about a particular market service related to given service is applied and regarding the real observations of the market the value of the un-priced parameters is determined (4).

On the other hand, through stated preferences approach an imaginary market is designed for an un-priced service and then the people are asked about their willing to pay (WTP) or willing to accept (WTA) to improve or not improve the quality of given service. According to this method, after designing the imaginary market, public demand for a given service or commodity is measured through their opinions (extracted from the questionnaires). The most common method to achieve stated preferences is to conduct interviews about their WTP and WTA level to maintain or improve the quality of studied service or commodity.

The information extracted through revealed preference offers a perception about a quality in present conditions of the market, technology, and policy making, while those obtained from stated preference not only are very useful in these studies but also can be still applied by a change in the mentioned parameters; i.e. technological advances and managerial policies, etc. (5).

Determination of vehicles tolls depends on to economic and social characteristics of the citizens, on one hand, and traffic properties and congestion of the studied area, on the other hand; where both of these cases are variable with time. For instance, once changing the location of study area from one city to another, many of these properties are subjected to the changes. The specified characteristics about information gathered by RP approach, as well as people and authorities’ unfamiliarity with pricing policies and taking such tolls emphasize importance of SP approach in this research.

The methodology utilized in this study is formed through definition of a circle around central area of the city. This circle surrounds the old and highly congested area of the city that accommodates different land use. The appropriate approach for congestion pricing in the study field is to consider vehicle mode, the used route, as well as entering time and day to the study area. To determine users’ WTP and then detection of the share of using private cars in each congestion pricing scenario, some questionnaires were designed through SP approach. The questionnaire comprises three parts including private information, travel chain information, and pricing scenarios. Questioning process was performed through random interview in destinations inside the circle and then database was formed. Design of pricing scenarios was conducted through efficient design approach, while citizens’ WTP was done through MNL models.

**CASE STUDY**

Tehran, capital city of Iran, is 15th most populated city globally. Based on the census performed in 2011, Tehran’s population is 12,183,391 where 8,293,140 of them live in the city. Tehran experiences a high volume of traffic congestion in its routes. There are two permanent traffic restriction programs. The first one is congestion pricing, while the latter was based on vehicles’ plate number.

Between 2003 and 2005, due to frequent pollution reports from some central parts of the city and heavy traffic flow in central streets of the city, the authorities tried to develop a large area with traffic restrictions over the city and drive people toward use of public transportation facilities.

This situation, coupled with the growing demand for using private vehicles and inadequate capacity of the new routes and streets, produced a more complicated traffic state of Tehran, particularly in its central section. The critical increase of pollution level, particularly in the winter, and air inversion phenomenon over the
past years has made the schools and all other activities off for several days. The mentioned points caused the authority to think of a novel plan to prevent or reduce traffic volume induced by private vehicle. In 2005, turnpass of the vehicles – based on their plate number – was proposed. Now, this restriction is operated at 6:30-19:00 from Saturday to Wednesday and at 6:30-13:00 in Thursday, while in off days traffic over the city is always free. It is worth to mention that Thursday and Friday are weekends in Iran.

The population studied was passengers who tend to enter to this circle. To collect data in this investigation, a SP questionnaire was designed, which consists of three separate parts to gather the following information:

- Information about private, social, and economic specifications of travellers
- Trip Information of travellers
- Information concerning participant responses to the policies/changes in trips to study area

The first part of the questionnaire contains demographic information such as gender, age, education level, number of family members, number of vehicles and neighbourhood address. The second part contains information such as the possibility, time, and access to public transportation, travel time, trip purpose, and the number of occupants in the same day trip. In the third part pricing scenarios are introduced. Thus, interviewees select their preferred vehicle to do their trip in the same day considering the proposed congestion pricing for each scenario. The number of scenarios for each questionnaire was four, while to estimate suitable price three types of questionnaire were designed. The main difference in these questionnaires was congestion pricing in their scenarios.

The broadness of study area caused various vehicles are placed in study area of this research. Besides, this vastness comprises a wide range of people from various classes in terms of income and social welfare level. In this regard, as shown in Figure 1, the inside parts of the zone were divided into 11 to 17 zones which contain old and dense central areas of the city with main office and commercial use. Also, zones 1 to 10 are among highly congested areas of the route network of the city, which involve a more diverse land use and performance level in the network. The boundaries between these zones are made of the routes with higher performance level as an appropriate segregation between the zones is created in terms of areas, routes network, and socioeconomic specifications of the residents. Inquiry process was performed through interview in destination within two separate days. To perform inquiry, 23 trained questioners were employed. 783 questionnaires were selected after processing and elimination of incomplete ones.

Since the circle comprises the dense texture and city and also involves office and commercial users, it was expected that trip for work purpose is a major share (60.5%) of the interviewees’ purpose. The other purposes including purchase, doing private chores, and education were in the next places – 12.5%, 11.2%, and 11.2%, respectively. The dominant pattern in each of mentioned travel objectives corresponded with the present pattern in comprehensive transportation and traffic system of Tehran.

The following items are choices of each interviewee in using the SP questionnaires in the study circle:

- Alternative 1 (Do nothing): pay the congestion pricing and doing the trip at peak hours
- Alternative 2: doing the trip at non-peak hour and paying less tolls
- Alternative 3: paying no congestion pricing (out of congestion pricing time or forego trip)
- Alternative 4: taxi and motorcycle
- Alternative 5: bus and subway

Based on the choices listed in Table 1, the database information was cumulated and after their validation and correlation control between the variables, various utility functions were designed and finally table function was selected as the ultimate function.
### TABLE 1: Utility Functions of Different Alternatives

<table>
<thead>
<tr>
<th>Details</th>
<th>Coefficients</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>**P[Z&gt;</td>
<td>z]</td>
<td>Value**</td>
</tr>
<tr>
<td><strong>ALTERNATIVE 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The tolls charged for entering to the traffic area in peak hours</td>
<td>0.000</td>
<td>-0.00028</td>
</tr>
<tr>
<td>The average price of the vehicle (in million Rials)</td>
<td>0.061</td>
<td>0.00534</td>
</tr>
<tr>
<td>Group 1: 6, group 2: 16, group 3: 45, and group 4: 90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designed parameter: Education years</td>
<td>0.000</td>
<td>0.08175</td>
</tr>
<tr>
<td>1: 10 years, 2: 15 years, 3: 18 years, 4: 23 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designed parameter: If the job is freelance work, 1 if not then 0</td>
<td>0.001</td>
<td>0.33435</td>
</tr>
<tr>
<td>Per capita vehicle ownership (the number of vehicles divided into number of family members)</td>
<td>0.008</td>
<td>0.59405</td>
</tr>
<tr>
<td><strong>ALTERNATIVE 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tolls rate during nonpeak hours</td>
<td>0.000</td>
<td>-0.00038</td>
</tr>
<tr>
<td>Designed parameter: Gender</td>
<td>0.001</td>
<td>-0.80377</td>
</tr>
<tr>
<td>If the gender is male 1, if not then 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designed parameter: If the job is clerk, 1 if not then 0</td>
<td>0.091</td>
<td>-0.51387</td>
</tr>
<tr>
<td>Target variable: Compulsory trip (work and educational)</td>
<td>0.081</td>
<td>-0.4488</td>
</tr>
<tr>
<td><strong>ALTERNATIVE 3</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant value</td>
<td>0.059</td>
<td>-0.68225</td>
</tr>
<tr>
<td>Designed parameter: Marital status. If married, 1 if not then 0</td>
<td>0.000</td>
<td>0.80014</td>
</tr>
<tr>
<td>Designed parameter: Privately employed. If privately employed, 1 if not then 0</td>
<td>0.000</td>
<td>-0.70089</td>
</tr>
<tr>
<td>Designed parameter: Age from 33 to 45</td>
<td>0.020</td>
<td>0.32645</td>
</tr>
<tr>
<td>Designed parameter: If the residence is placed out of circle, then 1 if not then 0</td>
<td>0.002</td>
<td>0.47839</td>
</tr>
<tr>
<td>Designed parameter: Entering to the traffic area before once</td>
<td>0.051</td>
<td>-0.29675</td>
</tr>
<tr>
<td>The number of family members</td>
<td>0.000</td>
<td>-0.3359</td>
</tr>
<tr>
<td>The average price of the vehicle (in million Rials)</td>
<td>0.008</td>
<td>-0.01711</td>
</tr>
<tr>
<td>Group 1: 6, group 2: 16, group 3: 45, and group 4: 90</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ALTERNATIVE 4</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The time interval to reach to the first public transportation station</td>
<td>0.017</td>
<td>-0.01364</td>
</tr>
<tr>
<td>Average travel time from origin of the trip to destination (min)</td>
<td>0.000</td>
<td>-0.00712</td>
</tr>
<tr>
<td>Target variable: Compulsory trip (work and educational)</td>
<td>0.002</td>
<td>0.27158</td>
</tr>
<tr>
<td>Designed parameter: Education level is BA or higher</td>
<td>0.012</td>
<td>-0.21605</td>
</tr>
<tr>
<td>Designed parameter: If the job is clerk, 1 if not then 0</td>
<td>0.000</td>
<td>0.42926</td>
</tr>
<tr>
<td>Designed parameter: Residence in zones 1 to 10</td>
<td>0.001</td>
<td>0.27955</td>
</tr>
<tr>
<td>Residing in zones 1 to 10, 1 if not then 0</td>
<td>0.000</td>
<td>-0.15583</td>
</tr>
<tr>
<td>Number of occupants</td>
<td>0.000</td>
<td>-0.15583</td>
</tr>
<tr>
<td><strong>ALTERNATIVE 5</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designed parameter: Passing the distance between the vehicle and first station If passed on foot, 1 if not then 0</td>
<td>0.000</td>
<td>0.65167</td>
</tr>
<tr>
<td>Designed parameter: Access to both plate numbers, 1 if not then 0</td>
<td>0.000</td>
<td>-0.91584</td>
</tr>
<tr>
<td>Designed parameter: If the job is clerk, 1 if not then 0</td>
<td>0.001</td>
<td>-0.34585</td>
</tr>
<tr>
<td>Number of occupants</td>
<td>0.000</td>
<td>-0.15583</td>
</tr>
<tr>
<td>Designed parameter: Stop during the travel Having stop, 1 if not then 0</td>
<td>0.023</td>
<td>-0.18505</td>
</tr>
<tr>
<td>Designed parameter: The expensive price of the vehicle If it is expensive, 1 if not then 0</td>
<td>0.000</td>
<td>-0.71338</td>
</tr>
<tr>
<td>Designed parameter: Using public transportation system If using the transportation system, 1 if not then 0</td>
<td>0.000</td>
<td>0.61309</td>
</tr>
<tr>
<td>Designed parameter: Residence in zones 11 to 17, 1 if not then 0</td>
<td>0.003</td>
<td>0.42135</td>
</tr>
</tbody>
</table>
The parameters for model fitness control are introduced in Table 2. In this regard, logarithm of the likelihood function can be obtained in three states of assuming all parameters as zero ($L(0)$), all parameters as zero except constants of utility function (market share $L(C)$, and model soundness ($L(\beta)$). The table shows that the parameter $2[L(\beta) - L(0)]$, with $\chi^2$ distribution and $N - m + 1$ degree of freedom (where $N$ is the number of selected variables of the given vehicle), rejects the zero state of parameters by confidence level above 99%. Besides $2[L(\beta) - L(0)]$, with $\chi^2$ distribution and $N - m + 1$ degree of freedom (where $m$ is the number of selected vehicles, indicate that the designed model is superior to the market share model. The values of fitness index $\rho^2$ and likelihood level of the models are also contained in the table. In this regard, $\rho^2$ values are suitable based on the number of selected models in the level of multivariate selection models. The likelihood level of the models is 51%. Considering the 5-choice structure of the circle models, and knowing that likelihood percentages are obtained based on complete possibility of each item, the model seems sound and valid.

### TABLE 2: Validation Variables for Vehicle Selection Models

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Obs.</td>
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</tr>
<tr>
<td>Number of independents Variables</td>
<td>31</td>
</tr>
<tr>
<td>$L(0)$</td>
<td>-6443.16</td>
</tr>
<tr>
<td>$L(C)$</td>
<td>-5128.97</td>
</tr>
<tr>
<td>$L(\beta)$</td>
<td>-4328.43</td>
</tr>
<tr>
<td>$\rho^2$</td>
<td>0.328</td>
</tr>
<tr>
<td>$2[L(\beta) - L(0)]$</td>
<td>1601.08</td>
</tr>
<tr>
<td>$2[L(C) - L(\beta)]$</td>
<td>4229.46</td>
</tr>
<tr>
<td>$\chi_{0.99}^2(N)$</td>
<td>52.18</td>
</tr>
<tr>
<td>$\chi_{0.99}^2(N+m+1)$</td>
<td>47</td>
</tr>
<tr>
<td>Percent Correct</td>
<td>51</td>
</tr>
</tbody>
</table>

### RESULTS ANALYSIS

One of most important parameters about change of traffic tolls is its share in decrease of travel demand to the traffic area by private vehicle. Although various social, economic, and political parameters should be considered in determination of tolls rate, control of citizens' PTW and, as a consequence, deciding to change travel vehicle from private to public is an appropriate guide in these kinds of decisions.

To conduct this analysis, all variables were considered in their medium level and demand flexibility was analyzed with respect to tolls rate. To analyze price sensitivity at peak hours, non-peak toll rates were considered in their ground level. Demand variation diagram through using private vehicles in different toll rates in the studied circle is shown in Figure 2.

By taking 30,000 Rials from the users, demand level for using private vehicles drops below 49%. These conditions are rather similar to the current conditions, where daily half of vehicles are allowed to enter to traffic area. Since the goal is to improve traffic volume compared to the present situation, it is not recommended to determine a rate which leads to demand increase up to 50% and this rate should be considered as the bottom price. Once the fee increases up to 70,000 Rials, another 25% of the demand for private vehicle reduces and the share of private vehicle reaches to 26%. Finally, 135,000 Rials for congestion pricing only 6% of the private vehicles enter to the traffic area.

The alternative of changing trip time to free of charge hours (before 6:30 and after 19:00) or giving up the travel involves low flexibility; as by increase of congestion pricing to 140,000 Rials the share of this alternative changes only 5%. Therefore, shifting travel time to hours out of pricing period is not a pleasant alternative to the users; although it seems that travellers may select this alternative. Also, the alternative which indicates change of travel time to non-peak hours has low share and flexibility. Purchase and leisure trips may usually have the potential of time change Also, among the compulsory trips a slight share of them have such a potential.

### CONCLUSION

Travellers’ behaviour toward congestion pricing in central parts of Tehran city has been studied. An area with high congestion has been selected through an imaginary circle and then SP questionnaire has been designed to study travellers’ behaviour and completed in various destinations in the study area through interviews. In the questionnaire, the scenarios are designed in a way that they cover all potential alternatives for travellers that should enter the congestion pricing area. The alternatives were cumulated in five groups and the utility functions and the share of each group has been determined using MNL model.

The results indicate that for 135,000 Rials congestion pricing, 95% of travellers with private vehicle will shift their mode to taxi and motorcycle or to public transportation including bus and subway. The zones 1 through 10 with more residential land use compared to zone 11 to 17, higher commercial land use, have lead travellers to travel at non-peak hours without congestion pricing.

Based on sensitivity analysis of the results, by increase of congestion pricing a significant share of private mode
choice (without change of trip time) shift to public transportation (bus and subway) and taxi. This modal shift happens in a rather equal ratio for both public and taxi systems. However, bus and subway is a more preferred alternative compared to the taxi. Development of public transportation facilities for the users has led to easier and convenient access to transit mode and is considered the main factor for such an output in these models.

FIGURE 2: Shares of Various Modes Regard to Congestion Pricing Scenarios in Peak Hours

REFERENCES
Adaptive Traffic Signal Control Pilot Project for the City of Surrey

Main Author:
Perry Craig
Senior Principal
Delcan Corporation
p.craig@delcan.com

Co-Authors:
Sinisa Petrovic
Traffic Operations Manager
City of Surrey
smpetrovic@surrey.ca

Joseph K. Lam
Managing Director
Delcan Corporation
j.lam@delcan.com

This project was carried out by Delcan Corporation under contract with the City of Surrey. Delcan is a multi-disciplinary engineering and technology company. In March 2014, Delcan was acquired by Parsons Corporation, an international engineering, construction, technical, and management services firm, with more than 15,000 employees and 3,000 projects worldwide. Delcan has joined a company that has been in business for nearly 70 years and has a long, proud history of delivering successful projects and answering some of the toughest challenges in the industry.

ABSTRACT
With continued rapid growth of the City of Surrey in British Columbia, there is a need for a better cost effective method to efficiently manage traffic demand. The City applied for and secured funding from Transport Canada under the Strategic Highway Infrastructure Program to deploy an Adaptive Traffic Signal Control (ATSC) Pilot Project. The City and Delcan partnered to implement and evaluate the ATSC Pilot Project using Delcan’s “Multi-criteria Adaptive Control” system.

Seven signalized intersections along 72nd Avenue corridor between 120th Street and King George Boulevard are controlled by BiTrans Type 170 traffic signal controllers and monitored by the City’s McCain “QuicNet” traffic signal management system. The scope of the ATSC Pilot Project was to demonstrate the integration of traffic adaptive control with existing traffic signal control infrastructure, and to evaluate benefits of adaptive control. The Pilot Project demonstrated seamless integration of ATSC system with existing traffic signal control infrastructure.

INTRODUCTION

Project Background
The City of Surrey has been the fastest-growing municipality in British Columbia, Canada over the past decade. To manage this growth, the City regularly reviews and updates the pre-determined time based coordinated (TBC) signal timings on its major traffic corridors within its 250 signal network (Figure 1). To combat the aging of their signal timing plans and reduce the cost of manual updates, the City is looking for an automated method to keep up with the rapid traffic growth and more efficiently manage the traffic demand.

The proposed initiative is the deployment and evaluation of Adaptive Signal Control Technology (ASCT) as an enhancement to the City’s existing traffic signal control system. Through the adaptive signal control technology, signal timings will be automatically adjusted and adapted to variable traffic demands measured by on-street vehicle detectors in real time. This mode of control typically reduces delays compared to traditional coordinated signal timing plans, and keeps pace with traffic growth.
FIGURE 1: Signalized Intersection within the City of Surrey

FIGURE 2: Signalized Intersection Locations Along 72nd Avenue Corridor

Project Objectives
The objectives for this ASCT Pilot Project are to implement adaptive signal control technology on a pilot corridor in Surrey and demonstrate that ASCT:

- Integrated with existing traffic signal management infrastructure
- Easy and cost-effective to deploy
- Performs as well as the best optimized TBC signal timing plans
- Responds to random fluctuations in traffic patterns and unplanned incidents/events

Proposed Adaptive Signal Control Technology
Delcan proposed to implement their Multi-criteria Adaptive Control (MAC) system that has been designed to take advantage of modern technologies and address the limitations of existing commercially available adaptive signal control systems. System and operational benefits that Delcan’s MAC include:

- Multi-criteria adaptive signal control algorithms that cater for a wide range of traffic conditions
- Distinctive adaptive signal control criteria applied to optimize signal timings for the prevailing traffic
- Flexible detector configuration requirements that enable users to optimize detector coverage, minimizing capital costs, for better data collection
- Reduced effort to update and maintain signal timing plans
- Improved traffic operational efficiency and reduced traffic congestion
- Open system architecture compatible with the ITS Architecture for Canada that can provide for integration and data sharing with other ITS initiatives in the region
- Open system architecture and communications protocol

PROJECT DESCRIPTION

Pilot Project Location
To select the Pilot Project corridor, potential corridors within the City of Surrey were screened according to the following criteria:

- The corridor must be subjected to variable traffic flows
- The signalized intersections (7-10) should be relatively closely spaced
- Communications with the traffic signal controllers along the corridor must either be existing, or easily achieved
- No construction will occur on site during the study

The corridor that best met these criteria and was thus selected for the ASCT Pilot Project was the 72nd Avenue corridor between 122nd Street and 134th Street (Figures 2). The selected corridor is comprised of the following seven closely spaced signalized intersections: 122nd Street; 124th Street; 126th Street; 128th Street; 130th Street; 132nd Street; and 134th Street.

Along 72nd Avenue, the traffic signal controllers typically operate under TBC control during high volume periods (e.g., weekdays from 6:30 am to 7:00 pm). Outside of these weekday periods, the controllers typically operated as fully actuated (e.g., from 7:00 pm to 6:30 am the following day).
Traffic signal operations along 72nd Avenue are currently well coordinated. The seven signalized intersections are all relatively evenly spaced, traffic volumes are generally manageable, and the TBC signal timing plans employed by the City provide good operational service. While there are some salient traffic generators within this corridor, such as a shopping mall, a polytechnic university, and a secondary school, and special events that impact traffic do occur, there currently are no recurring congestion problems being experienced along the corridor.

The seven signalized intersections along 72nd Avenue are controlled by Type 170 traffic signal controllers (running McCain (formally BiTrans) 233 firmware), and monitored by the City’s McCain “QuicNet” traffic signal management system.

**ASCT Pilot System Architecture**

Delcan’s Multi-criteria Adaptive Control (MCAC) system is a network-based, multi-level hierarchy of data processing nodes, acquiring traffic information from the field devices – traffic signal controllers and vehicle detectors – and implementing intersection signal timing parameters modified to respond to and improve the traffic conditions in the supervised traffic area.

**MAC Algorithms**

The algorithms within MCAC cater for a wide range of traffic conditions; from light traffic to over-saturated and congested situations. They collect and process traffic flow data acquired from the signalized intersections in the given signal group, and then calculate the cycle length, splits and offsets for all traffic signal controllers in the group, on a cycle-by-cycle basis. Distinctive traffic signal control criteria (i.e., maximum green bandwidth, minimum delays and stops, queue balancing, and gating) are applied to optimize the signal timings for the prevailing traffic conditions.

Upon initialization, MCAC algorithms retrieve road network configuration, intersection phases, and algorithm parameters from the configuration database. This information is used to allocate data structures for intersections, links, phases and vehicle movements.

**ASCT Pilot System Architecture**

Delcan’s Multi-criteria Adaptive Control system (MCAC) was designed to integrate and work with existing traffic signal management systems such as the City’s existing “QuicNet” system, Type 170 traffic signal controllers, and communications network. The MCAC system is also flexible to work with the City’s existing in-ground, circular-shaped, stop line vehicle detector loops as well as with the City’s tree topology communications network. From a functional perspective, the MCAC system can be structured at three different levels; namely:

- Central MCAC processing level, consisting of the central processor, database and graphic user interface (GUI)
- Field (MCAC Adaptor) level, with processing provided by MCAC adaptors installed in roadside controller cabinets
- Client user interface level, at one or more operator workstations through a GUI interface

Figure 3 illustrates the architecture implemented for the City of Surrey ASCT Pilot Project.

**System Integration and Testing**

**Micro-simulation Environment**

Before on-street operation, a custom micro-simulation environment was developed to test and verify the ASCT, and calibrate the parameters used in the ASCT algorithms. The AM Peak period was modeled to create a representative test case for testing and configuring the adaptive signal control operations.

The ability to review the operations of the network as a whole was considered to be a significant advantage of the micro-simulation model, which provided insights that could not be seen through field observations, and a useful tool for the fine tuning the ASCT parameters. The simulation model also provided confidence in the proposed operations prior to deployment in the field.

**Communications Network**

The ASCT system was integrated to work with the City’s existing communications network. The City employs a tree topology network, with a leased line from the control centre to a “master” intersection in the field, and then both point-to-point and multi-drop spread.
spectrum radio links from the “master” intersection to the other local traffic signal controllers. From the central ASCT system, the network operates like a multi-drop serial network. This interface between the central ASCT system and the MAC Adaptors in the field was successfully shown to work in the field trial tests.

**OPERATIONAL PERFORMANCE**

*Evaluation Methodology*

After the ASCT Pilot Project system was operational under the production environment, field observations and fine-tuning of the system were conducted. Before-and-after travel time and queue length surveys were subsequently undertaken for evaluating the performance of the pilot system under real traffic conditions.

*Field Operational Observations*

From field observations made during the deployment and testing of ASCT, the ASCT system was observed to correctly react to traffic trends to provide optimized cycle lengths, phase splits, and offsets. In particular, ASCT was observed as appropriately responding to unexpected and unplanned events such as heavier volumes due to a special event or an incident. One such example (Figure 4) was observed on the evening of August 2nd, 2012, when as illustrated in Figure 7, the ASCT system response matched the volume trend during the PM Peak period. The traffic volumes on that day remained high until after 8:00 pm (due to a nearby special event), and the ASCT responded by correspondingly keeping the cycle length higher for longer than would normally have been the case under TBC operations.

**Figure 4: Total Approach Volumes vs. Adaptive Cycle Lengths for 122nd Street**

Total intersection traffic volumes at 128th Street and the corresponding ASCT-calculated controller cycle lengths between 7:00 am and 7:00 pm are illustrated in Figure 5 for a typical day, Tuesday, October 23, 2012. (In the chart, the right axis is the cycle length, and the left axis is the volume in vehicles per cycle.) From this graph, the following salient points are noted:

- The ASCT-calculated cycle lengths follow the general volume trend and change in a timely manner
- In the middle of the day, the cycle length tends to stay at the configured minimum cycle length value of 90 s; reflecting the relatively low traffic volumes
- When the current cycle length provides adequate capacity there is seldom a need to increase the cycle length in response to minor fluctuations in traffic demand

**Field Operational Performance**

*Vehicle Travel Time Surveys*

*Survey Procedure*

Travel time data was collected in October 2012, by test-car runs utilizing an average car technique that required the surveyor to travel according to the speed that the majority of vehicles were travelling. Both eastbound and westbound travel times between the successive signalized intersections were measured along 72nd Avenue. Each travel time survey was conducted on a typical weekday in the AM Peak, Off Peak and PM Peak periods. For each time period, the survey was continuously carried out for two hours by making round trips back to the original starting point.

*Comparison of Results*

The following Measures of Effectiveness (MOE) were obtained from the before and after data:

- Average travel time savings
- Average travel speed
- Average vehicle stops
- Average vehicle delay

The initial benefits of ASCT that can be immediately measured in a pilot project directly depend on the initial base case. For the City of Surrey ASCT Pilot Project, the base case was optimized TBC timing plans. From the survey results summarized in Table 1 below, it can be seen that the differences between TBC and ASCT are very minimal. A statistical analysis of the before and after travel time data was therefore conducted to test whether the after survey data was significantly different from the before survey data.
**TABLE 1: Travel Time Survey Results (Combined for both Eastbound and Westbound)**

<table>
<thead>
<tr>
<th></th>
<th>TBC</th>
<th>ASCT</th>
<th>Difference</th>
<th>Difference (%)</th>
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<tr>
<td><strong>Average Travel Time (s)</strong></td>
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<tr>
<td>AM Peak</td>
<td>272</td>
<td>276</td>
<td>4</td>
<td>1%</td>
</tr>
<tr>
<td>Off Peak</td>
<td>330</td>
<td>333</td>
<td>3</td>
<td>1%</td>
</tr>
<tr>
<td>PM Peak</td>
<td>306</td>
<td>320</td>
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<td>5%</td>
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<tr>
<td><strong>Average Travel Speed (km/h)</strong></td>
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<td></td>
</tr>
<tr>
<td>AM Peak</td>
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<td>0%</td>
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<td>Off Peak</td>
<td>32</td>
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<tr>
<td>PM Peak</td>
<td>33</td>
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<tr>
<td><strong>Average Vehicle Stops (No)</strong></td>
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</tr>
<tr>
<td>AM Peak</td>
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<td>4%</td>
</tr>
<tr>
<td>PM Peak</td>
<td>79</td>
<td>83</td>
<td>4</td>
<td>5%</td>
</tr>
</tbody>
</table>

**Weeknight and Saturday Traffic**

In addition to the weekday timing plans, the City of Surrey implements weekend timing plans on some key corridors where there is significant commercial activity. Along 72nd Avenue, a weekend plan is deployed from 10:00 am to 6:00 pm on Saturdays. Outside of this period, the controllers are operated as fully actuated.

The ASCT system was observed to appropriately respond to heavier traffic volumes generated by commercial activity on weeknight evenings and on Saturdays. One such example was observed on Saturday, November 3rd, 2012 (Figure 6), the traffic volumes typically increased through the day until about 4:30 pm, and ASCT responded to follow the trend by increasing the cycle length during the afternoon.

**FIGURE 6: Total Approach Volume vs. Actual Cycle Length for 128th Street**

Note that the graph plots the actual cycles implemented by the controller on the street. During ASCT operations, the controller is also configured to enable semi-actuated operations for the minor phases, and as a result, the reported cycle lengths can vary higher or lower than the ASCT configured maximum and minimum cycle lengths.

**CONCLUSIONS AND LESSONS LEARNED**

**Conclusions**

- System Integration – The open system architecture design provided for the seamless integration of the ASCT system with the City’s existing system
- Integration with Existing Traffic Signal Controllers – The ASCT and MAC adaptors were successfully integrated and proven to work with the City’s existing Type 170 traffic signal controllers
- Integration with Existing Wireless Communications Network – The ASCT and MAC adaptors were successfully integrated and proven to work with the City’s existing tree topology communications network
- On-street Operational Performance – The ASCT performed equal to the best optimized TBC signal timing plans
- ASCT Operations – Intersection queue length studies and historical volume data show that the ASCT system correctly reacted to changes in real-time traffic demands to provide optimized cycle lengths and phase splits
- Evening and Saturday Traffic – The ASCT system was observed to appropriately respond to heavier traffic volumes generated by shopping trips on off peak times
- Incidents and Special Events – The ASCT system appropriately responded to incidents and special events that resulted in unexpectedly heavier traffic volumes

**Lessons Learned**

- To maximize the benefits of deploying ASCT, arterial corridors and signalized intersections with more highly variable and/or unpredictable traffic volumes should be selected as preferred locations.
- The ASCT system successfully optimized the signal timing plans with minimal additional vehicle detectors
- To best optimize controller offsets, a recommended future system enhancement would be for the system to predict the average link travel speeds based on real-time field measurements
- In configuring the ASCT system, the maximum cycle length was restricted to the same maximum value that had been implemented for the TBC timing plans
- The length of the arterial corridor was too short for definitive before and after vehicle travel time
comparisons. With a typical total travel time of 4 to 6 minutes, any potential differences in travel times under the different modes of control were hidden within the normal corridor travel time variations

- The local traffic signal controllers spent an unexpectedly large amount of the time in transition when implementing new timing plan changes, which could diminish the efficiency of the ASCT operation

- Robust and reliable communications between the Central Server and all MAC Adaptors in the field is a key consideration in the deployment of the ASCT system

- A micro-simulation test environment is excellent for reviewing network traffic flows, intersection offsets, vehicle queues, etc.

**Economic Benefits**

Assuming an approximate travel time along the 72nd Avenue corridor of 300 s per direction, then over the five year period, the average driver would have incurred an additional 225 seconds of delay per day or 15.6 hours of delay per vehicle. If the timing plan was updated every two and a half years, which is about the best that any municipality could typically achieve, then the additional delay caused by the aging timing plan would be 18.75%; equivalent to 7.8 hours of delay per vehicle per round trip over a 5-year period.

Conservatively assuming an average demand along the 72nd Avenue corridor of 600 trips per hour over the highest 11 hours of the day, at a cost of $10 per hour, would result in the additional delay costing $514,800 over a 5-year period (or $1,029,600 over a 10-year life cycle of the adaptive system), in addition to the cost of retiming the traffic signals.
Lessons Learned From a Large Scale Wireless Deployment for Traffic Management in New York City

Main Author:
Robert Rausch
Vice President
TransCore ITS
robert.rausch@transcore.com

ABSTRACT
New York City decided to upgrade traffic control systems and field equipment and turned to a wireless system using the National Transportation Communications for ITS Protocol (NTCIP) ensuring interoperability between vendors and the flexibility offered by a wireless infrastructure. Changes to the NTCIP standards were required and the large scale purchase and implementation of thousands of traffic controllers throughout the City were addressed. The implementation includes over 9500 controllers using a wireless network to single traffic control computer system using exception based reporting. During the next eight months additional controllers were installed with the goal of bringing 12,400 signalized intersections under central computer control. This system now provides adaptive control and traditional traffic responsive and time-of-day scheduled pattern changes. The City is now implementing and testing a centralized Transit Signal Priority (TSP) system using this wireless network, with modifications to the NTCIP standards (1211) to support remote TSP activation.

SHIFT TO WIRELESS CONTROL
As the City was upgrading its infrastructure of traffic controllers, it was being forced to abandon the concept of data communications using leased facilities to the traffic controllers. An extensive study determined that wireless communications would provide the features needed at a cost considerably less than their existing DC interconnect and the Manhattan coaxial cable network. NYCDOT carried out a complete request for information (RFI) with inputs from a number of wireless system suppliers and wireless systems integrators.

However, as other agencies were also looking into the possibility of developing their own wireless network, the Department of Information Technology and Telecommunications (DoITT) determine that it would be better for the City to consider the deployment of its own city-wired, shared wireless network to support/ meet the needs of traffic control and the evolving needs of other agencies such as the police department, the fire department, department of sanitation, and others to support vehicle location services and emergency management applications. The system was also designed to support video surveillance, as well as traffic control.

THE PROBLEMS ENCOUNTERED
Unlike IP and other types of wired communications, a large scale wireless network can be subject significant variations in the latency of the communications. We have observed that with NYCWiN (essentially a private 3G network), the latency of the communications from the traffic management center (TMC) to the field controllers can vary significantly; while the latency is normally 165 to 350 milliseconds, a small portion of the messages do not get received by the TMC for server seconds. In general, it was not possible to reliably poll the traffic controllers at a once-per-second rate to achieve second-by-second data fidelity. Where most wire-line system today poll the intersections once per second, the bandwidth consumed by the traffic controller application would be prohibitive and virtually lock out other lower priority applications.

To resolve this problem, the NTCIP standards were modified (reference NTCIP 1103) to support the concept of exception based reporting (EBR). With this approach, the intersection only transmits data to the TMC when something “changes” at the intersection. Thus, for a 90 second cycle, which is commonly used in Manhattan, there are 10 changes of state per cycle. Each “change” denotes a change in the field display: green1, yellow1, red1, green2, yellow2, red2, walk1, fdw1, walk2, and
Some are simultaneous while others may be independent. In order to maintain second-by-second monitoring accuracy, the TMC would need to transmit 90 poll messages and receive 90 response messages for a total of 180 messages in 90 seconds just to monitor the signal display changes. With EBR, if there are 10 changes per cycle, then there would be 10 messages per cycle since each includes a time stamp. This saves more than 94% of the bandwidth required.

The EBR mechanism is based on the concept of trap channels – each trap channel includes the IP address where the data is to be sent and various channel parameters such as retry timers, anti streaming parameters, and a channel status.

The central system configures trigger conditions that can be used by the local controller to determine when to send a message to the TMC and what information to transmit when the trigger is detected. For example, the trigger could be periodic and in the case of NYC, we configure a detector data reporting period and tell the ASTC to report all of its vehicle data accumulation buffers when the trigger occurs. For phase changes, the TMC configures which changes are to trigger a transmission and what is reported when it transmits. Thus, the traffic controller (ASTC) can be configured to report all or some state changes.

Each trap channel includes a buffer where the messages are queued, and as new triggers occur, a new message is added to the queue. There are two different channel types: 1) channels that transmit and wait to be acknowledged, and 2) channels that transmit regardless of whether the central system hears the message. As a result, each trap channel has a status flag indicating that it is: A) ready, B) pending (awaiting a response when required), C) error (no acknowledgement has been received and the number of retries has reached its limits). To keep this working properly, the ASTC is configured to transmit a heartbeat trap at 45 second intervals and the contents of the heartbeat trap is the trap channel status for all of the trap channels configured. Thus, as configured events are triggered, the appropriate report block is placed on the trap message queue and when the channel is in the Ready state, the message is transmitted. The channel then enters the Pending state where it waits for the TMC to reset its status flag to the Ready state and this process repeats until there are no entries on the queue. When the TMC detects the Error statue, it simply resets to the Ready state thus freeing the trap channel to send its queued traps one at a time.

**SYSTEM FEATURES**

**Automatic Synchronization**

To minimize the impact of communications failures on the overall traffic conditions, the central system was modified to include a feature that would synchronize the time-of-day schedule in the traffic controllers with the time-of-day schedule used by the central system. In the absence of central computer control, the local traffic controllers revert to local time-of-day schedules and as long as the schedules are consistent with the normal traffic flow, the traveling public is unaware of any communications or system failures. Thus, whenever the operators update the timing patterns on the central computer, they are automatically formatted and downloaded to the field controllers.

**Adaptive Control**

The NTCIP is built on the concept of configuring the timing patterns at the traffic controllers and relying on the central system to select one of the timing plans based on traffic conditions or the time-of-day schedule. When the timing patterns are “downloaded” this information is “burned” into FLASH RAM so that in the event of a power failure, the patterns are retained. The NTCIP standards did not make provisions for dynamic plan changes. For NYC, working with the vendor, Peek Traffic – USA, we were able to add the concept of dynamic timing patterns which are not stored in the FLASH RAM but take over as long as the controllers have power (or does not experience a power outage > ½ second). The central system now includes an adaptive algorithm (ACDSS) that adjusts the split between phases over the short term and adjusts the cycle length and offset on a longer time frame. Since these changes are held in dynamic RAM, the life of the unit remains unaffected by cycle-by-cycle changes.
**Time Synchronization**

In order for the field controllers to remain synchronized and to continue signal progression, one of the main tasks for the central system is to set and verify the local “clocks”. Once set by the TMC, the ASTC maintains its timing accuracy by using the power line as its reference which is guaranteed to maintain a consistent time; although it may “wander” + or – several seconds from a standards based time reference. The power company counts cycles and will keep the clocks within several seconds of the accurate time.

The mechanism for downloading the time-of-day to the traffic controllers had to be adapted to take into account the latencies of the communications media; the NTCIP did not include support for a Network Time Protocol (NTP) therefore, the operation of the central system now checks the acknowledgement received from the ASTC for sub-second responses.

**Timeout Features**

The system makes extensive use of the timeout features of the central command to change timing patterns. The NTCIP variable “unitBackupTime” was used extensively to ensure that actions directed by the central system would terminate after a period of no communications from the TMC. In addition, the NTCIP was modified to timeout the memory management feature (Database management) such that download operations that were interrupted would not be left “hanging” until communications was restored thereby causing unpredictable results.

**Remote Transit Signal Priority (TSP)**

Most TSP systems utilize the concept of a localized trigger point physically located upstream of an intersection. Then the transit vehicle (bus) reaches the trigger point, a sensor either at the controller or in the roadway detects the presence of the bus and begins the process of modifying the signal operation to “assist” the transit vehicle in traversing to and through the intersection. This custom block was implemented for the wireless network and includes the following parameters:

- Input number – the specific scenario requested might include a protected left or through movement, or queue jump etc.
- Command – initiate request, clear an existing request
- Estimated time of arrival
- Time to live – the time after which (seconds) the command is to revert to normal operation
- Vehicle information: type, priority, location (Latitude, Longitude), speed
- Time to apply – which is the time to actually apply the call input to the traffic controller

While there have been other papers describing the transit signal priority system and the results to date, the interesting issue related to the communications was the time to apply; this is an absolute time – Universal Time Code – that sets the exact time that the TSP request is to be processed by the controller; if the controller receives the request before the time, it waits until the time is reached. If it receives it after the time, it applies the input immediately. The system was designed with a 2 second communications delay tolerance such that any delays up to 2 seconds do not adversely affect the operation. All other timing is relative to this time.

It was found that this has achieved the goal of providing the necessary advance warning to the intersection at the right time about 99% of the time.

**System Error Status**

With a system the size of New York, it was found that it was difficult to relate the operational status of all intersections. Further, we were experiencing issues with the traffic controllers routinely failing communications approximately once per hour – although not all at the same time. A communications failure status is now written to the main system log on a once per minute basis and captures the current state of all intersections. This status variable contains a count of all intersections that are off-line for each minute and this has provided us with the ability to notice trends and problems and to take immediate corrective actions.

The chart below is an example that shows a daily failure log and the overall system status. Note that the network operator experienced weather related issues with the microwave backhaul network. This is the failures for a system with ~9500 intersections active. The chart below shows the typical distribution of the uptime for the intersections on the system.
Analysis Tools
In addition to the above, the traffic control system provides a complete spreadsheet each week showing the uptime and number of failures experienced by each traffic controller throughout the City. This information is combined (fused) with the equipment uptime for the network operator and provides a snapshot of the system operation for the week. Figure 3 above shows the snapshot for the week for the uptime of all of the traffic controllers. By combining this with the data from the equipment monitoring system used by the network operator, the City can more efficiently troubleshoot problematic locations and understand which locations need additional antennas or where adjustments are required for the wireless network.

The network operator has now agreed to export their equipment status in real time so that it can be integrated into the traffic control system real-time displays. This will allow the operator to review both the communications uptime and the traffic controller uptime on the same screen and allow the operator to “reset” the field wireless router without contacting the network operations center. This also allows the graphic overlay of the cell sites and the cell structures (sector RF coverage) so that the TMC personnel can better support field maintenance and troubleshooting activities.

Automated Configuration
One of the major issues with a system this size is configuration management with a large number of field maintenance crews. At any given time there are typically 8-10 field crews in the city performing a combination of routine maintenance and corrective maintenance activities. Each cabinet has been configured with an embedded 16-bit cabinet address that is used by the system to create the IP address of the cabinet. Whenever a technician replaces either the wireless router or the traffic controller, an automated configuration process takes over. The router polls the traffic controller (broadcast ping) to learn the controller’s IP address, then the wireless router uses this information to communicate with the network operations center (NOC) to verify the authority of the ASTC to join the network and the authenticity of the router. Once verified, the database is automatically downloaded for the controller and the technician can start normal operation. Note that all of this occurs without operator intervention – hence, no operator error.

Reset Database Action
The EBR database configuration is very complex and uses a combination of the event structure (NTCIP 1201 and NTCIP 1103) and the variables for signal controllers (NTCIP 1202). What was discovered is that in order for
the EBR to function properly, all tables had to be cleared. The original NTCIP design for EBR did not include a “reset” function, which meant that the TMC had to clear all possible entries in the trap tables.

Working with the vendor, a single command was added to the EBR support that allows the central system to “reset” the entire EBR database structure to its virgin condition ready to be configured. This simplified the configuration process.

**SUMMARY**

Deploying a citywide traffic management system for New York City has been a significant challenge. The biggest challenge was using the wireless network to manage the communications while compensating for the anomalies experienced with such a network. This has been a slow process extending from its beginning in 2008 for the ITS world Congress and culminating with the installation of over 10,000 traffic controllers by this November.

The characteristics of a wireless network has meant that certain polling was not possible, yet the agency wanted to continue to ensure that it was receiving once per second data fidelity. This necessitated changes to the NTCIP to support to include time-out parameters for selected operations and supports the exception based control with full recovery procedures.

After more than 4 years of operation, the City now has about 10,000 controllers on-line and routinely experiences about 200 failures at any instant in time. Of those 200 failures, more than 2/3 are basically long term failures as the result of power access problems, construction activities, or RF problems necessitating the replacement of the antenna. With less than 1% in a failure condition, and a 2 hour MTTR for the field contractors, the wireless approach has proven to be far more reliable that the coaxial cable plat or the leased facilities from their common carrier. The system has been adapted to support maintenance by field contractors and added network debugging and maintenance tools to the traffic control system.

**REFERENCES**

1.  www.ntcip.org
2.  www.ite.org/standards
3.  www.nema.org
King Saud University Traffic and Parking Study

Main Authors:
Ali Saleh, PE
TEC Engineering, Inc.
alis@teceng.com

Alex Hanna, PE
Khatib & Alami, CEC
ahanna@kacec.com

Michael J. Hafner, PE, PTOE
TEC Engineering, Inc.
mhafner@teceng.com

Corresponding Author:
Sara Senger, PE, PTOE
TEC Engineering, Inc.
ssenger@teceng.com

ABSTRACT
The rapid growth of King Saud University (KSU) campus and hospital facility within the university boundaries has given rise to challenges in their transportation network. The administration conducted a study of the existing/future traffic circulation and parking demands. A consulting team composed of TEC Engineering, Khatib & Alami, and members of the KSU faculty was established to undertake the study.

The KSU Traffic and Parking Study was accomplished in four phases. The 1st phase included an assessment of existing conditions and the development of a travel demand forecasting model. The 2nd phase of the project involved development and testing of alternative solutions. The 3rd phase of the project conducted the necessary land survey, produced all engineering designs and related technical specifications and computed cost estimates for the execution of selected projects. In the 4th phase of the project, the team prepared final drawings, plans, and bid documents.

INTRODUCTION
The Directorate of Projects and Maintenance at KSU contracted with the consulting team of Khatib & Alami Saudi Consolidated Engineering Company and TEC Engineering, Inc. to prepare a transportation study to evaluate the traffic and parking within the university and make recommendations to accommodate future expansion.

The goal of the traffic and parking study was to accommodate existing and projected growth. The objectives included:

- A study of the current condition of traffic and relevant parking
- An analysis of the current and future conditions after review of projects/trends
- Identify solutions for traffic, accidents and congestion
- Evaluate and provide engineering design plans for improvements to the network

The KSU Traffic and Parking Study was a four phase project. The 1st phase included an assessment of existing conditions and development of a travel demand forecasting model. This phase revealed existing operational and safety deficiencies, but are not limited to the following:

- Geometric design/capacity issues along major intersections on KSU Ring Road
- Safety concerns of high travel speeds
- Parking congestion issues with inadequate access and circulation
- Pedestrian deficiencies in existing parking lots and areas outside of the campus core
- Limited administrative policies related to traffic management

The 2nd phase of the project involved development and discussion of alternative solutions to mitigate the existing concerns and manage the future conditions of the transportation network within campus. The
travel demand forecasting model was fine-tuned and used to project traffic demand. A set of alternatives was developed to address anticipated network deficiencies. The alternatives developed were detailed and discussed in the Phase II report. All alternatives were then compared and advantages and disadvantages of each finalized. At the conclusion of this work, a final Phase II report was delivered, documenting all findings and tasks associated with this phase.

In the 3rd phase the project team performed all necessary land survey, produced all engineering designs and related technical specifications, provided a detailed plan of required directional and traffic signs, prepared plans for development of vacant areas, and provided cost estimates for execution of the selected alternative. This phase documented all activities associated with this task. The 4th phase included preparation and submission of all final drawings and plans.

The KSU Traffic and Parking Study is a comprehensive study including origin and destination surveys, traffic counts, parking surveys and observations, and examination of future plans in order to assess traffic and parking needs. This study included a travel demand forecasting model and analysis of alternative scenarios.

**REVIEW OF EXISTING CONDITIONS**

**Geometrics and Capacity**

The project team completed a field review of the King Saud University network. The results of the field observations combined with the review of geometric, signing, and pavement marking standards were used in the evaluation of the existing transportation infrastructure at KSU. Each major intersection was evaluated. Specific issues regarding geometric layout, sight distance/visibility, traffic control signage, and pavement markings were examined. Issues regarding pavement conditions throughout the entire roadway network (rutting, cracking, shoving, etc.) were also reviewed. The project team conducted a review of all of the signalized intersections within the campus. This review included inventorying the controller types, and verifying the traffic signal phasing.

**Pedestrian Facilities**

The network of pedestrian facilities within the KSU academic core is well-defined. However, the overall heat of Riyadh makes walking on campus a strenuous task and not the primary mode of transportation. When considering future improvements, it is important to consider that every driver that enters the campus and parks becomes a pedestrian who must be accounted for and adequate facilities must be available. The pedestrian facilities are structured around a north south spine. The ‘spine walkway’ is a pedestrian highway with perpendicular walkways connecting core buildings. The buildings are then connected to various parking lots. The spine walkway is approximately twenty meters wide, supplying adequate capacity for the student and faculty. It is open-aired and provides shade from the heat.

**Parking Facilities**

The use of off-street parking in the various parking lots at KSU was found to be very mixed. Some areas experience heavy parking while other areas experience little or no usage. Guiding motorists to the proper parking lot and available parking spaces could improve off-street parking on campus. Policy recommendations were also considered such as assigning specific lots to user groups or implementing time limit restrictions for certain parking areas to increase turnover.

**Transit**

The preferred mode of transportation to/from campus, as well as within campus is by private automobiles. The students/faculty/staff that use public transportation is very small, which is a reason why congestion on campus is so high. Results from the O/D surveys indicated that only 3% of those interviewed used public transportation.

**TRAVEL DEMAND FORECASTING MODEL**

A travel demand forecasting model was created for campus. The model uses a four-step model process containing: trip generation, trip distribution, mode choice, and assignment. The model is constructed in a way to allow for scenario analysis based on the adjustment of activities, transport facilities, or both.

The KSU model uses an innovative approach to simulate parking lot usage throughout the day by tracking available parking stalls in lots and updating the assignments hourly throughout the day. This strategy also allows the user to track those who drive and walk as a part of their journey in the KSU model network from those who only walk. This method employs running hourly static assignments and saving the parking lot usage statistics as the input for the next hour.

Traffic counts were coded for all links that had data available. It is best to have directional, peak hour counts for a peak hour model. These were supplied from tube counts and intersection turning movement counts completed as a part of this project. Directional counts were required on all links that connect the model to the external world. Count data was entered for the AM Peak, Mid-Day Peak, PM Peak, and daily volumes. In addition,
counts for the pedestrian movements were input into the KSU model. The pedestrian movements were used to verify that the model had a good approximation with observations.

![FIGURE 1: King Saud University Model Domain](image)

Land uses in the model were determined through demographics data and the University’s GIS data. The land use information was input into the transportation analysis zone by category for trip generation purposes. During the model development process, the land use data was reviewed for proper application within the model. Land use categories were crafted in the model to allow flexibility in analyzing forecast scenarios. Forecast land use data in the KSU model allows for alternative scenarios to be evaluated for transportation impacts so an understanding of the resultant impact is considered.

**ALTERNATIVE SOLUTIONS TO ADDRESS DEFICIENCIES**

Based upon the evaluation of existing conditions completed during the initial phases of the project, several deficiencies in the transportation system were noted. These deficiencies can be grouped into three categories: Traffic Concerns, Safety, and Parking. Based on these problem areas, the project team established goals and objectives in order to develop a set of action items which, when implemented in tandem, will address the existing deficiencies in the transportation network.

The roadway network is the backbone of the transportation infrastructure. All improvements that will be required to adequately manage the projected growth of the campus will be dependent on the roadway network structure. Before the project team could evaluate the impact of potential projects and select those most advantageous for implementation at the University, the network for which all improvements will be built upon needed to be determined. If the network layout of the University cannot adequately handle the projected vehicular growth, then regardless of the improvements placed upon it, the overall goal of safe and efficient traffic flow cannot be achieved. The existing conditions results showed a serious need to tackle road problems given the weak presence of public transportation in the City of Riyadh. Two roadway network schematic solutions were considered and evaluated using several measures of effectiveness to determine which was the most advantageous.

**Roadway Network Schematic Solutions**

Schematic Solution 1 consists of the baseline existing vehicular network, which utilizes a ring road structure. This solution represents a standalone internal connected roadway network, meaning that once vehicles enter the campus gates, they can maneuver throughout all parts of the university without having to exit and utilize the external roadways which are typically congested and cause significant delays. For the development of this solution, improvements are proposed to the existing infrastructure to mitigate existing known traffic problems and to handle the projected traffic growth throughout the University. New roadways will be kept to a minimum and all existing gates will remain. Intersection improvements and traffic management infrastructure will be the primary geometric improvement projects associated with this solution.

The primary improvements in Schematic Solution 1 include:

- New north-south connector road between the Villas area and northern roundabout
- Potential grade-separation of emergency access and Book Gate intersections
- Revised parking access and layout
- Traffic calming measures
Schematic Solution 2 consists of creating a roadway system that separates areas of the campus into zones. Each zone would have its own internal roadway network and no public connectivity between zones will be provided. Travel between zones would require use of the external roadway network outside the campus gates or through internal transit modes. Each zone would have a primary arterial roadway to serve internal zone traffic movements. Collector roadways would branch out from the main arterial route to service the residential neighborhoods and the campus parking areas assigned to each zone. This solution was developed primarily to improve the following situations:

- Poor gate distribution with existing roadway network: As indicated in the existing conditions analysis, existing gate usage distribution is poor. Schematic Solution 2 was developed with limited connectivity to attempt to achieve an improved overall gate distribution.
- Cut-through traffic concerns: The supervisory committee indicated many times to the project team the problems created due to cut-through traffic. Schematic Solution 2 was developed to significantly eliminate the cut-through potential while still providing distinct zones with internal circulation.
- Medical City/campus traffic conflicts: Existing conditions analysis indicated that heavy traffic volumes in the area of the medical city create poor operating conditions. Schematic Solution 2 creates a separate medical city access and zone to help eliminate these conflicts. Solution 2 model results improve the operations within the medical city.
- Safety issues within the curve southeast of medical city area: Schematic Solution 2 removes/restricts this portion of the roadway network to special use only.

**Measures of Effectiveness Comparison**

The project team coded, analyzed, and evaluated the network schematic solutions. Measures of effectiveness were developed to evaluate and compare the network schematic solutions. This comparison allowed for the selection of the optimum network solution for which future roadway and intersection improvement projects can be developed to service and maintain operations throughout the University. Table 1 summarizes measures of effectiveness, point scoring, and evaluation of each network schematic solution.

The results of the MOE evaluation indicate that Schematic Solution 1 is the optimum solution. Schematic Solution 1 will be cost-effective and least disruptive to existing operations, also providing the best projected operations in terms of travel and delay. The two solutions were compared in the travel demand model and the results clearly show that the existing internal connected network layout and infrastructure provides the most advantageous backbone with which to build upon. Intersection and roadway improvement projects were developed and analyzed to improve the conditions along the KSU Ring Road and throughout campus utilizing the existing roadway network. Additionally, projects relating to addressing parking deficiencies, reducing cut through traffic, introducing transit and ITS were also identified.
### TABLE 1: Measures of Effectiveness Summary

<table>
<thead>
<tr>
<th>Measures of Effectiveness</th>
<th>Solution 1</th>
<th>Solution 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Internal</td>
<td>Completely Isolated</td>
</tr>
<tr>
<td></td>
<td>Connected Network</td>
<td>Isolated Network</td>
</tr>
</tbody>
</table>

#### Traffic Management / Circulation Policies

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Provide and maintain a circulation system that meets the current and future needs of the University</td>
<td>Intersection peak hour levels-of-service (Highest Hourly Peak)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Levels-of-service on roadway segments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Construction disruption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vehicle Kilometers of Travel (VKmT) system-wide (Daily)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vehicle Hours of Travel (VHT) (Daily)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Estimated cost of roadway network improvements</td>
</tr>
<tr>
<td>2</td>
<td>Separate Medical City traffic from other University related traffic as much as possible</td>
<td>Intersection peak hour levels-of-service (emergency access traffic signal)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Levels-of-service on roadway segments (adjacent roadway - Medical City area)</td>
</tr>
<tr>
<td>3</td>
<td>New street networks should minimize cut-through traffic in the University and minimize the need for traffic control devices</td>
<td>Potential to reduce cut-through traffic (directness of route)</td>
</tr>
<tr>
<td>4</td>
<td>Improve the safety of pedestrian and vehicular traffic on the university network</td>
<td>Average delay / vehicle (system-wide)</td>
</tr>
</tbody>
</table>

Sub-Total: 32 27
Weighted Score: 30 26

#### Parking Management Policies

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Designate parking areas on campus and consider assigned parking based on user group</td>
<td>Ability to implement</td>
</tr>
<tr>
<td>2</td>
<td>Provide adequate parking spaces for all user groups / facilities</td>
<td>Parking supply / demand</td>
</tr>
<tr>
<td>3</td>
<td>Provide access and connectivity between parking areas</td>
<td>Accessibility</td>
</tr>
</tbody>
</table>

Sub-Total: 11 8
Weighted Score: 24 18

#### Transportation and Community Policies

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Recognize the relationship between transportation systems and their impact on the quality of life at KSU City</td>
<td>Average delay / vehicle (system-wide)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vehicle Kilometers of Travel (VKmT) system-wide (Daily)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vehicle Hours of Travel (VHT) (Daily)</td>
</tr>
</tbody>
</table>

Sub-Total: 9 3
Weighted Score: 20 7
Total Score (out of 100): 75 50
IDENTIFICATION OF POTENTIAL PROJECTS

Table 2 depicts projects/improvements that were considered/evaluated for KSU.

**TABLE 2: Potential Projects**

<table>
<thead>
<tr>
<th>Geometrics/Operations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve existing deficiencies</td>
<td>Roundabout size</td>
</tr>
<tr>
<td></td>
<td>Roundabout approaches</td>
</tr>
<tr>
<td></td>
<td>Intersection alignment</td>
</tr>
<tr>
<td></td>
<td>Sight distance/visibility</td>
</tr>
<tr>
<td></td>
<td>Lighting</td>
</tr>
<tr>
<td>Expand/upgrade pedestrian facilities</td>
<td></td>
</tr>
<tr>
<td>Traffic signal improvements</td>
<td>Upgrade traffic signal equipment</td>
</tr>
<tr>
<td></td>
<td>Traffic signal operations updates</td>
</tr>
<tr>
<td>Conversion of selected intersections to alternative operation</td>
<td></td>
</tr>
<tr>
<td>Major intersection reconfiguration of selected intersections</td>
<td></td>
</tr>
<tr>
<td>Construct central connector road</td>
<td></td>
</tr>
<tr>
<td>Major capacity improvements on KSU Ring Road</td>
<td></td>
</tr>
<tr>
<td>Parking</td>
<td></td>
</tr>
<tr>
<td>Reconfigure parking lots</td>
<td>Academic areas</td>
</tr>
<tr>
<td></td>
<td>Medical city area</td>
</tr>
<tr>
<td>Parking assignment (lot use)</td>
<td></td>
</tr>
<tr>
<td>Automated Access to VIP parking areas</td>
<td></td>
</tr>
<tr>
<td>Install or upgrade existing guard booths in parking areas</td>
<td></td>
</tr>
<tr>
<td>Install covered walkways for pedestrians from parking lots to Spine Walkway (buildings)</td>
<td></td>
</tr>
<tr>
<td>New parking lot construction/multi-story parking structures</td>
<td></td>
</tr>
<tr>
<td>Relocate parking lots outside of core campus (outside KSU Ring Road)</td>
<td></td>
</tr>
<tr>
<td>Parking Management System - see ITS</td>
<td></td>
</tr>
<tr>
<td>Circulation</td>
<td></td>
</tr>
<tr>
<td>Restrict cut through traffic by installing 'University Traffic Only' signs</td>
<td></td>
</tr>
<tr>
<td>Restrict cut through traffic by installing midblock checkpoints</td>
<td></td>
</tr>
<tr>
<td>Traffic calming measures at problem areas</td>
<td></td>
</tr>
<tr>
<td>Improve circulation at King Saud Educational Complex</td>
<td></td>
</tr>
<tr>
<td>Reconfigure KSU Ring Road access points for redeveloping areas of campus</td>
<td></td>
</tr>
<tr>
<td>Signing/Pavement Markings</td>
<td></td>
</tr>
<tr>
<td>Develop and implement a way finding system for the campus.</td>
<td></td>
</tr>
<tr>
<td>Upgrade traffic related signage</td>
<td>Primary locations</td>
</tr>
<tr>
<td></td>
<td>Secondary locations</td>
</tr>
<tr>
<td>Install pavement markings using City of Riyadh standards - KSU Ring Road</td>
<td></td>
</tr>
<tr>
<td>Continued maintenance of signage and pavement markings</td>
<td></td>
</tr>
<tr>
<td>Transit</td>
<td></td>
</tr>
<tr>
<td>Provide a shuttle service between residential and core areas of campus</td>
<td></td>
</tr>
<tr>
<td>Implement a shuttle service through parking lots to spine walkway</td>
<td></td>
</tr>
<tr>
<td>Designate taxi stands and pick-up/drop-off areas</td>
<td></td>
</tr>
<tr>
<td>Provide a transit link between the girls campus and the medical city</td>
<td></td>
</tr>
<tr>
<td>Expand transit service along KSU Ring Road to provide full campus coverage of transit. Link the system to the ADA proposed light rail system along King Abdullah/Olaya-Al Batha Roads</td>
<td></td>
</tr>
<tr>
<td>Install Personal Rapid Transit (PRT) along the Spine Walkway in the core of campus</td>
<td></td>
</tr>
</tbody>
</table>
To address the major problem areas identified in the existing conditions evaluation (traffic concerns, safety, and parking), multiple improvements must be combined and implemented. The project team identified actions, which could be taken on as potential projects on campus (Table 2). They were all evaluated based on their ability to advance the objectives of the project. The schematic (Figure 4) depicts major projects recommended to address geometrics, parking, circulation, transit initiatives, and ITS. The outcome of the study was a list of projects for implementation, as well completion of the final design plans which can be used to construct the recommended projects. Implementing these projects will provide a multimodal transportation network that will serve its faculty, students, and staff both now and in the future. A prioritization of the multimodal network projects recommended for implementation is provided in Table 3 on facing page.

### TABLE 2 (continued): Potential Projects

<table>
<thead>
<tr>
<th><strong>Intelligent Transportation Systems (ITS)</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Deploy a University Transportation Management Center (UTMC)</td>
<td>Provide campus security</td>
</tr>
<tr>
<td>Deploy field devices on the KSU Ring Road</td>
<td>Monitor and manage traffic</td>
</tr>
<tr>
<td>Deploy additional field devices where necessary</td>
<td>Respond to incidents</td>
</tr>
<tr>
<td>Install communication backbone</td>
<td>Manage special events</td>
</tr>
<tr>
<td>Advanced Parking Management Systems (APMS)</td>
<td></td>
</tr>
<tr>
<td>Information dissemination</td>
<td></td>
</tr>
<tr>
<td>Transit system integration</td>
<td></td>
</tr>
<tr>
<td>UTMC - Riyadh integration</td>
<td></td>
</tr>
<tr>
<td>Technology refresh</td>
<td></td>
</tr>
<tr>
<td><strong>Intelligent Transportation Systems (ITS)</strong></td>
<td></td>
</tr>
<tr>
<td>Deploy field devices on the KSU Ring Road</td>
<td>Cameras</td>
</tr>
<tr>
<td>Deploy additional field devices where necessary</td>
<td>Detectors</td>
</tr>
<tr>
<td>Install communication backbone</td>
<td>Dynamic Message Signs (DMS)</td>
</tr>
<tr>
<td><strong>Advanced Parking Management Systems (APMS)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Intelligent Transportation Systems (ITS)</strong></td>
<td></td>
</tr>
</tbody>
</table>

The KSU Traffic and Parking Study provided a comprehensive look at current and future conditions. Not only were geometric and roadway improvements considered, but enhancements to parking, pedestrian accommodations, and ITS. The major outcome of the study were the development of multi-modal recommendations for the KSU network and the creation of design plans used to implement the recommended projects.

### DESIGN OF PROPOSED IMPROVEMENTS

Once the recommended projects were reviewed and approved by members of the KSU faculty assisting on this important project, design plans were completed. The existing campus was surveyed to provide a basemap for engineering plans to be developed. Designs were completed for all recommendations listed in Table 3 above for three horizons: short term improvements (5 years), medium term improvements (5-10 years), and the long term improvements (10-20 years). Technical specifications, cost estimates, and bidding documents were developed for each set of horizon plans.
<table>
<thead>
<tr>
<th>Location</th>
<th>Project/Improvement</th>
<th>Time Frame for Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Connector Road</td>
<td>Construct North-South Connector Road</td>
<td>Within 5 Years</td>
</tr>
<tr>
<td>Villas Traffic Signal</td>
<td>Split Intersection Design</td>
<td>Within 5 Years</td>
</tr>
<tr>
<td>Emergency Access Intersection</td>
<td>Single Loop Interchange</td>
<td>Within 5 Years</td>
</tr>
<tr>
<td>King Khalid Hospital Traffic Signal</td>
<td>Single Loop Interchange Modifications</td>
<td>Within 5 Years</td>
</tr>
<tr>
<td>Service Gate Traffic Signal</td>
<td>Geometric Improvements</td>
<td>Within 5 Years</td>
</tr>
<tr>
<td>College of Administration Science Intersection</td>
<td>Convert to Traffic Signal</td>
<td>Within 5 Years</td>
</tr>
<tr>
<td>Traffic Signal Improvements</td>
<td>Implement Project</td>
<td>Within 5 Years</td>
</tr>
<tr>
<td>Book Gate Roundabout</td>
<td>Single Loop Interchange</td>
<td>Within 12 Years</td>
</tr>
<tr>
<td>Printing &amp; Press Roundabout</td>
<td>Convert to Traffic Signal</td>
<td>Within 12 Years</td>
</tr>
<tr>
<td>Eastern Roundabout</td>
<td>Traffic Signal with Restricted Northbound Leg</td>
<td>Within 20 Years</td>
</tr>
<tr>
<td>Student Accommodations Roundabout</td>
<td>Roundabout Modifications to Improve Safety</td>
<td>Within 20 Years</td>
</tr>
<tr>
<td>Northern Roundabout</td>
<td>Convert to Traffic Signal</td>
<td>Within 20 Years</td>
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<tr>
<td>Reconfigure Parking Lots</td>
<td>Implement Project</td>
<td>Within 5 Years</td>
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<tr>
<td>Specific Area Parking Supply</td>
<td>Construct Necessary Parking Structures</td>
<td>Within 5 Years</td>
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<tr>
<td>Parking Assignment (Lot Use)</td>
<td>Implement Project</td>
<td>Within 5 Years</td>
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<tr>
<td>Automated Access to VIP Parking Areas</td>
<td>Implement Project</td>
<td>Within 5 Years</td>
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<tr>
<td>Install Covered Walkways for Pedestrians</td>
<td>Implement Project</td>
<td>Within 5 Years</td>
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<tr>
<td>Install or Upgrade Guard Booths in Parking</td>
<td>Implement Project</td>
<td>Within 20 Years</td>
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<tr>
<td>Future Parking Lot Construction</td>
<td>Construct additional 800 student parking spaces and additional 1230 Faculty/Staff/Employee/Administration spaces.</td>
<td>Within 20 Years</td>
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<tr>
<td>Relocated Parking Lots Outside of Core Campus</td>
<td>Examine policies that restrict core campus parking for certain user groups</td>
<td>Within 20 Years</td>
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<tr>
<td>Restrict Cut Through Traffic with Signs</td>
<td>Install signs to supplement more restrictive measures</td>
<td>Within 5 Years</td>
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<tr>
<td>Restrict Cut Through Traffic with Midblock Access Checkpoints</td>
<td>Implement Project</td>
<td>Within 5 Years</td>
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<tr>
<td>Traffic Calming Measures at Problem Areas</td>
<td>Speed Tables where necessary</td>
<td>Within 12 Years</td>
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<tr>
<td>Improve Circulation at King Saud Educational Complex</td>
<td>Shuttle Service and Revise Educational Complex Roadway System</td>
<td>Within 12 Years</td>
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<tr>
<td>Manage KSUC Ring Road Access Points for Redeveloping Areas of Campus</td>
<td>Consider Access Management in Future Development</td>
<td>Within 20 Years</td>
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<tr>
<td>Develop &amp; Implement a Wayfinding System for Campus</td>
<td>Implement Project</td>
<td>Within 12 Years</td>
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<tr>
<td>Upgrade Traffic Related Signage</td>
<td>Implement Project</td>
<td>Coincide with geometric improvements</td>
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<tr>
<td>Install Adequate Pavement Markings</td>
<td>Implement Project</td>
<td>Coincide with geometric improvements</td>
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<tr>
<td>Continued Maintenance of Signage and Pavement Markings</td>
<td>Implement Project</td>
<td>Ongoing</td>
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<td>Residential to Academic Shuttle Service</td>
<td>Implement Project</td>
<td>Within 5 Years</td>
</tr>
<tr>
<td>Parking Lot Shuttle Service</td>
<td>Implement Project</td>
<td>Within 5 Years</td>
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<tr>
<td>Designate Taxi Stands and Pick-up/Drop-off Areas</td>
<td>Implement Project</td>
<td>Within 20 Years</td>
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<tr>
<td>Transit Link between Girls Campus and Medical City</td>
<td>Provide Girls Campus Shuttle</td>
<td>In place prior to Opening Day of Girls Campus</td>
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<tr>
<td>Deploy a University Transportation Management Center (UTMC)</td>
<td>Implement Project</td>
<td>Within 5 Years</td>
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<tr>
<td>Deploy Field Devices on KSUC Ring Road</td>
<td>Implement Project</td>
<td>Within 5 Years</td>
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<tr>
<td>Install Communications Backbone</td>
<td>Implement Project</td>
<td>Within 5 Years</td>
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<tr>
<td>Advanced Parking Management System (APMS)</td>
<td>Implement Project</td>
<td>Within 12 Years</td>
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<tr>
<td>Deploy Additional Field Devices where necessary</td>
<td>Implement Project</td>
<td>Within 20 Years</td>
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<tr>
<td>Information Dissemination</td>
<td>Implement Project</td>
<td>Within 20 Years</td>
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<tr>
<td>Transit System Integration</td>
<td>Implement Project</td>
<td>Within 20 Years</td>
</tr>
<tr>
<td>UTMC-Riyadh Integration</td>
<td>If Possible</td>
<td>Within 20 Years</td>
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<tr>
<td>Technology Refresh</td>
<td>As Needed</td>
<td>Within 20 Years</td>
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</table>
FIGURE 4: Multimodal Network Recommendations for KSU

King Saud University City Traffic and Parking Study
Phase II Final Recommendations
Multimodal Network Alternative 2

Legend

Control
A) Main Gate Intersection (Gate 1) – See Detail "A"
B) Service Gate 2
C) Multi-Purpose Sign – See Detail "C"
D) Multi-Purpose Sign – See Detail "D"
E) Central Connector Roadway (Gate 1) – See Detail "E"
F) College of Science Sign – See Detail "F"
G) Service Gate 3
H) Service Gate 4
I) Service Gate 5
J) Gate No. 3
K) Gate No. 4
L) Gate No. 5

Geometrics
A) Book Gate Intersection (Gate 1) – See Detail "A"
Section 8.1.5.1
B) Villas Intersection – See Detail "B"
Section 8.1.4.1
C) New Medical City Signal – See Detail "C"
Section 8.1.4.4
D) King Khalid Hospital Signal – See Detail "D"
Section 8.1.4.3
E) Emergency Access Intersection (Gate 2) – See Detail "E"
Section 8.1.5.2
F) College of Admin. Sciences Intersection – See Detail "F"
Section 8.1.3.4
G) Service Gate Intersection (Gate 3) – See Detail "G"
Section 8.1.4.2
H) Printing & Press Intersection (Gate 5) – See Detail "H"
Section 8.1.3.2
I) Northern Intersection – See Detail "I"
Section 8.1.3.3
J) Eastern Gate Intersection (Gate 4) – See Detail "J"
Section 8.1.3.1
K) Student Accommodations Roundabout – See Detail "K"
Section 8.1.2
L) Central Connector Roadway – See Detail "L"
Section 8.1.1
M) Reconfigure Parking Lots – See Detail "M"
Section 8.2.1
N1) Covered Walkways from Parking Areas to Buildings
N2) Spine Extension to Parking Garages
O) Future Surface Parking Lots
P) P1 – Student Parking Garage – Humanities Colleges (4200 Spaces)
P2 – Faculty/Staff Parking Garages (1650 Spaces combined)
P3 – Administration Parking Garages (1900 Spaces combined)
P4 – Medical City Parking Garage (1800 Spaces)
P5 – Student Parking Garage – Medical Colleges (1500 Spaces)
Q) Covered Faculty/Staff Parking Lots
R) Midblock Access Checkpoints – See Detail "R"
Section 8.3.1
S) King Saud Educational Center – Circulation Improvements – See Detail "S"
Section 8.3.2

Transit
T) Residential to Academic Area Shuttle
Section 8.5.1
U) Girls Campus Shuttle
Section 8.5.4
V) Park & Ride Lots w/Shuttle to Academic Area
Section 8.5.2
W) Designated Taxi Stands/Pick up & Drop off Areas
Section 8.5.3

Intelligent Transportation Systems (ITS)
X) University Transportation Management Center w/ associated peripherals
Section 8.6

General
Y) Pedestrian Buffer Zone
Section 8.1.6
Z) Future Academic Expansion Area

Details
SEPTEMBER 2014 – MAY 2016 IRF CALENDAR OF EVENTS

4th IRF Latin America Regional Congress
September 9–12, 2014
Lima, Peru

Executive Seminar Series:
Performance-Based Contracts
October 19–29, 2014
Orlando, Florida USA

1st IRF Asia Regional Congress & Exhibition
November 17–19, 2014
Bali, Indonesia

Executive Seminar Series:
4th Safer Roads By Design™: Across Six Continents
November 30 – December 9, 2014
Orlando, Florida USA

IRF Annual Meeting & General Assembly
February 23–25, 2015
Paris, France

Executive Workshop Series:
Roadside & Work Zone Safety
March 3–5, 2015
Lima, Peru

2nd Abu Dhabi Global Road Safety Forum
March 8–12, 2015
Abu Dhabi, UAE

Executive Seminar Series:
5th Safer Roads By Design™: Across Six Continents
March 15–25, 2015
Kuala Lumpur, Malaysia

Executive Workshop Series:
Proper Installation of Safety Devices
March 24–26, 2015
Sao Paulo, Brazil
During Brazil Road Expo 2015

4th IRF Middle East Regional Congress
April, 2015
Location TBD

4th IRF Caribbean Regional Congress
May 11–15, 2015
Georgetown, Guyana

Executive Seminar Series:
Performance-Based Contracts
May 17–27, 2015
Kuala Lumpur, Malaysia

Executive Workshop Series:
Safer Roads by Design™
Brazil Road Safety Association (ABSeV)
June 9–11, 2015
Sao Paulo, Brazil

1st IRF Brazil National Conference & Exhibition
August, 2015
Rio de Janeiro, Brazil

Executive Workshop Series:
Performance-Based Contracts
August 6–8, 2015
Toronto, Canada

Executive Seminar Series:
Meeting the UN Decade of Action Challenge
October 6–8, 2015
Santiago, Chile

Executive Seminar Series:
Performance-Based Contracts
October 18–28, 2015
Orlando, Florida USA

2nd IRF Africa Regional Congress
November, 2015
Yaoundé, Cameroon

Executive Seminar Series:
Public Private Partnerships
November, 2015
Kuala Lumpur, Malaysia

Executive Seminar Series:
6th Safer Roads By Design™: Across Six Continents
November 29 – December 9, 2015
Orlando, Florida USA

IRF Annual Meeting & General Assembly
January, 2016
Location TBD

Executive Seminar Series:
7th Safer Roads By Design™: Across Six Continents
March 6–16, 2016
Bali, Indonesia

5th IRF Caribbean Regional Congress
May 9–13, 2016
Location TBD

2014-2015 IRF WEBINARS

The IRF continues its initiative to provide world-class training content through web based media. Below is the 2014-2015 schedule of IRF eLearning Webinars. Webinars are complementary for IRF Members and can be viewed by non-members for US $129.

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January 29, 2014: Road Asset Management
March 5, 2014: Road Operations, Maintenance in PPPs
April 2, 2014: Emergency/Incident Management
May 7, 2014: Public-Private Partnerships
May 28, 2014: Sustainable Transport
June 25, 2014: Minimizing Fraud and Corruption
July 30, 2014: Highway Congestion Management
September 25, 2014: Asphalt Rubber
October 29, 2014: Bridge Maintenance & Inspection
December 10, 2014: Vulnerable Road User Safety

2015
January 28, 2015: Engineering Safer Roads
February 25, 2015: Road Financing & PPPs
March 25, 2015: Rural Road Maintenance
April 29, 2015: Advances in Flexible Pavements
May 27, 2015: Emergency / Incident Management 2
June 24, 2015: ITS Applications for Road Safety
July 29, 2015: Climate Change & Building Resilient Roads
August 26, 2015: Tunnel Safety
September 30, 2015: Management of Road Infrastructure
October 28, 2015: Funding Long-term Road Maintenance
November 18, 2015: Managing Mega Projects
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University of Central Florida

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