Module 3: Application of ITS to Transportation Management Systems

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Purpose

The purpose of this module is (a) to review the application of intelligent transportation systems (ITS) in the management of transportation facilities during recurrent and nonrecurrent conditions, (b) to identify the benefits of those applications, and (c) to highlight associated challenges and lessons learned. Transportation management systems (TMS) have a lot in common with transportation system management and operations (TSM&O), which is discussed in Module 4, “Traffic Operations.” This module focuses on the tools used in transportation management systems, whereas Module 4 focuses on operations and management strategies that use those tools to improve the performance of transportation systems. Simply put, this module describes the tools and the systems; Module 4 explains how to apply those tools and systems to get the best results. Therefore studying Modules 3 and 4 together will help practitioners gain a full appreciation of the tools and systems and get the best results from their use.

Objectives

After completing the module, you should be able to do the following:

- Understand the basic terminology and concepts of transportation management systems.
- Be familiar with the applications of ITS to the management of transportation facilities during recurrent and nonrecurrent conditions at such facilities.
- Explain highway system management data and the associated needs—data collection, data quality, data sharing, data archiving, and data analysis.
- Identify challenges and lessons learned associated with TMS.
- Discuss future actions in consideration of connected vehicle and highway systems.

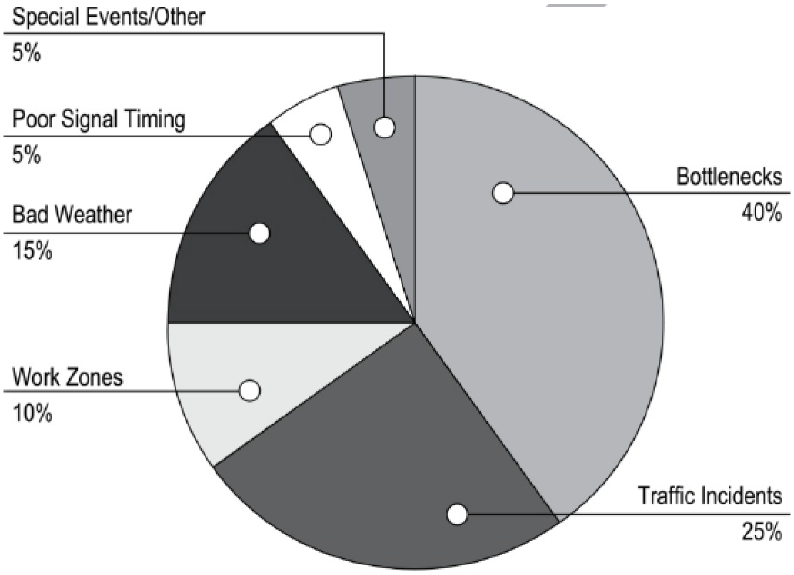
Introduction

This section discusses the basic functions of TMS, the importance of transportation management, and the relationship of TMS to the National ITS Architecture (NITSA).

Background

TMS have increasingly been considered to be crucial in operating and maintaining existing systems at acceptable levels. TMS implementation is necessary to mitigate congestion-related problems that occur because of constraints on the addition of new capacity. In addition, adding capacity does not necessarily resolve nonrecurring congestion problems due to incidents, weather, work zones, special events, and poor signal operation. Figure 1 shows the factors that contribute to the congestion problems that need to be addressed by TMS.[1]

Figure 1. Factors Contributing to Congestion[1]



It may be argued that TMS started in the early parts of the 20th century with the deployment of simple signal control. However, real efforts to develop and implement TMS can be traced back to the 1960s and 1970s. California conducted a ramp metering experiment in 1965 and deployed a fixed ramp metering system in 1967. The Los Angeles Surveillance and Control Project ramp metering program was launched and became operational in the early 1970s. In the 1970s, the Federal Highway Administration (FHWA) began developing computer-based signal control systems, providing another important basis for advanced traffic management as we know it now. With the advancement of computer and information technologies in the 1980s, various types of TMS strategies have started to be applied around the nation to address transportation issues associated with all transportation facility types and modes.

Basic Functions of TMS

A typical implementation of TMS involves one or more transportation management centers (TMCs), field infrastructure, and mobile units communicating in real time to monitor and manage transportation systems. A TMS can be for a single facility type or mode but it is more effective when applied to multiple facilities and modes in an integrated manner. Although, as discussed in this module, many types of transportation management systems exist, in general a TMS includes four functions, as shown in Figure 2:

- ***System Assessment:*** This function requires a data acquisition subsystem that consists of field devices or mobile units for video and data collection plus a central component for processing and archiving the collected data.
- ***Strategy Determination:*** This function involves making timely management decisions to address recurrent and nonrecurrent congestion based on the state of the current and predicted system to enhance the transportation system performance. The determination can be made manually by TMC staff, automatically by central and/or field software or firmware, or using a combination of the two. In the latter case, software modules provide support for the decisions of TMC staff. The real-time decision-making process and the information disseminated to other agencies and travelers can significantly improve the performance of the transportation system.
- ***Strategy Execution:*** This function involves the application of the decisions made by the strategy determination function. It generally includes commands sent by traffic management centers or field controllers to other centers, field devices, and/or mobile units.
- ***Strategy Evaluation:*** This function includes continuously (a) evaluating the performance of the system under the strategy implemented by the strategy execution function and (b) adjusting the implemented strategy and associated parameters in response to the evaluation results, based on an identified performance matrix. This evaluation and adjustment can be made in real time at short time intervals (e.g., every 1 to 15 minutes) or offline. Data archiving and decision support tools will have to be used to support this function.

Figure 2. The Basic Functions of Transportation Management Systems[2]

TMS Categories

Traditionally, TMS have been categorized based on the facility or the mode that they manage, such as freeway, arterial, transit, freight, and parking facilities. The recent trend in transportation management, however, is to effectively manage the transportation corridor or the network as an integrated system that includes combinations of modes and facilities. In this module, the management of other modes such as freight, transit, and nonmotorized transportation are not specifically discussed because they are addressed in other modules. However, these systems are described in this module and Module 4 when discussing integrated corridor management and other network management strategies, operation and management of regional transportation systems, and other topics that address multimodal transportation system management. Strategies that are normally considered TMS strategies, such as incident management and smart work zones, are discussed in Module 4, “Traffic Operations” but are only referenced in this discussion as needed.

Supporting Technologies

Categories of a TMS are based on the application and function of the supporting technologies. A TMS can be very complex with a large amount and various types of equipment deployed over large geographic areas, such as a region or a State. A TMS can also be limited to a local implementation of traffic management concepts at a specific location or at a facility to address specific identified needs. In all cases, the TMS is expected to deliver the four basic functions described earlier by integrating the various types of supporting technologies. Depending on the application, the supporting technologies may include infrastructure-based traffic detectors, closed-circuit television (CCTV) cameras, dynamic message signs (DMS), highway advisory radios (HAR), a communication subsystem, automatic vehicle identification (AVI), automatic vehicle location (AVL), central hardware and software, signal heads (for traffic signals and ramp meters), controllers, and gates, among other technologies. The discussion of supporting technologies in this module is related to their application and use in TMS and does not address the technological details and alternatives. These additional details can be found in Module 9, “Supporting ITS Technologies.”

Relationship of TMS to National ITS Architecture and Standards

The latest version of the NITSA, the National ITS Architecture Version 7, includes 26 traffic management service packages. In addition, a large proportion of the 11 public transportation system service packages in the NITSA deal with transit system management and multimodal coordination. Other packages related to TMS are also included as part of the commercial vehicle operations, emergency management, maintenance and construction management, and archived data management service areas of the architecture.

In addition to the ITS architecture, ITS standards are essential to a successful TMS implementation. Standards allow data to be shared between devices manufactured by different vendors, across different ITS applications, and between different agency systems. Another goal of ITS standards is to allow interchangeability of devices from different vendors. Of particular importance to TMS are the center-to-center and center-to-field standards referred to as the National Transportation Communications for ITS

Protocol (NTCIP). Detailed discussions of the ITS architecture and standards are presented in Module 2, “Systems Engineering.”

Information Collection

A critical component of all types of TMS is the information collection subsystem, which is used to assess the state of the system and to evaluate the management strategy (see Figure 2). This subsystem supports the detection of incidents, verification of incidents and attributes, monitoring of incident clearance, collection of special event information, transportation system control and warnings (e.g., ramp metering, signal control, lane control, variable speed limits, and queue warning), fleet performance tracking, travel time estimation and prediction, provision of data for planning and simulation, and performance measurement. Depending on the TMS category and application, the data collected by the information collection subsystem can include parameters such as volume, speed, occupancy, presence, fleet vehicle location, queue length, transit ridership, incident conditions, special events information, pavement conditions, and atmospheric conditions. Typically, the data is collected and in most cases uploaded to a central location at different aggregation levels; however, the data also can be used locally at a roadside controller. The collected information can be used in real time or archived for offline applications.

Information collection can be accomplished using manual methods, infrastructure-based traffic detectors, CCTV cameras, environmental sensing stations (ESS), automatic transit passenger counters, and probe surveillance technologies. Manual surveillance techniques can provide useful information and data to support transportation management, including information provided by fleet drivers (e.g., service patrols and bus and commercial vehicle drivers), other agencies, cellular calls, or call boxes. However, automatic data collection is generally also required to support TMS applications.

Infrastructure-based detection is described in the NITSA ATMS01 service package (Network Surveillance). The infrastructure detectors are sometime referred to as point detectors because they provide traffic parameters measured at a point. Depending on the specific TMS application and the detection technology used, the traffic parameters normally provided to traffic management software by infrastructure-based point detectors can include volume, speed, occupancy, presence, vehicle classification, and queue length. As currently implemented, many TMS applications, such as ramp metering and signal control, require volume and occupancy (or presence data) provided by point traffic detectors. Thus, the implementation of point traffic detectors is a major component of many applications of TMS, although advancements in connected vehicle technologies and the development of new TMS algorithms are expected to reduce the dependency on infrastructure detectors in the future.

One shortcoming of point detectors is that they have difficulty estimating travel time and speed based on point detections, particularly for arterial streets. Many detection technologies cannot accurately estimate performance measures at high congestion levels. For applications that require travel time and possibly origin-to-destination estimating, probe data collection technologies based on AVI technologies, such as electronic toll readers, Bluetooth readers, or automatic license plate readers; tracking based on AVL technologies; and private sector data can be good alternatives and increasingly have been used. Such data can also be used for other TMS applications, such as dynamic pricing, DMS messaging, and incident detection, if sufficient sample sizes of measurements for the application under consideration can be collected by the technology. The applications of AVI and AVL technologies to collect data, as described above, are presented as part of the ATMS02 Probe Surveillance in the NITSA. AVL technologies are also essential for tracking TMS vehicle fleets such as transit, commercial vehicle, and service patrols, allowing the monitoring and management of the fleets. However, AVI- and AVL-based technologies cannot provide the volume and occupancy data required for many current TMS applications, such as ramp metering and traffic signal control.

Private sector data providers have relied on combining information from a variety of sources (both infrastructure and mobile based). These providers have applied advanced data fusion methods in their estimation of travel time and have sometimes used O-D matrices. Examples of the data types used in these private sector applications include commercial fleet, taxi vehicles, consumer cellular global positioning system (GPS)-based devices, and GPS-based navigation systems. These are often combined with real-time traffic flow and incident information from TMS, sporting and entertainment events, weather forecasts, and school schedules.

CCTV cameras are also important components of TMS, allowing TMC operators to monitor and assess unusual conditions at highway facilities, on transit buses and stations, and at parking facilities. TMC operators can verify incident occurrence and clearance, incident information, road weather conditions, and field device status (e.g., DMS and signal status). This supports more effective responses to events with the appropriate level of resources and personnel. Typically, however, transit bus CCTV feeds are not viewed in real time because of bandwidth constraints in transit communication radios.

Weather-responsive transportation management and information systems are supported by environmental sensing stations (ESS).[3] An ESS is a fixed roadway location with one or more sensors measuring atmospheric, surface (i.e., pavement and soil), and hydrologic (i.e., water level) conditions. Data from these stations can be combined with data from weather services to provide inputs to transportation management and traveler information algorithms and methods.

Because of the different requirements for different TMS applications, TMS agencies should make informed decisions based on identified user needs and requirements regarding the types and application of the information collection technologies used. User needs should be captured in a concept of operation developed for the TMS. This also requires the examination of detection products, needed data types, reported and required accuracy and reliability, initial and recurrent costs, ease of use (installation, calibration, etc.), ease of integration with other components of the TMS, communication and power requirements, location and mounting requirements, and operation and maintenance requirements. Further discussion of existing information collection technologies can be found in Module 9, "Supporting ITS Technologies."

Freeway Management

Freeway management is the implementation of policies, strategies, and technologies to improve freeway performance. The objectives of freeway management programs include minimizing congestion (and its side effects), improving safety, and enhancing overall mobility and reliability[3]. The strategies discussed in this section are ramp metering, information dissemination, managed lanes, and other active traffic management systems. However, most of the other sections in this module and Module 4, "Traffic Operations", include strategies and technologies that support effective freeway management. For example, effective freeway management requires the implementation of an information collection system, transportation management center, incident management program, performance measurement program, and more.

Ramp Metering

Ramp metering (sometimes referred to as ramp signaling) is a type of ramp management that involves the use of a traffic signal installed at on-ramps to control the rate at which vehicles enter a freeway.[3,4] By controlling this rate, the throughput of freeway traffic can be increased by reducing density and conflicts in the outside lanes. This in turn improves the mobility and reliability of freeway facilities. Ramp metering is covered in ATMS04 in the NITSA.

Ramp metering is not the only ramp management strategy. Other management strategies include the following:[4]

- Ramp closure during severe events such as traffic incidents, adverse weather, planned special events, and fire or smoke.
- Preferential treatments such as high-occupancy vehicle (HOV) bypass lanes, HOV-exclusive ramps, and emergency vehicle–exclusive ramps.
- Signal control strategies at off-ramps (see Figure 3).
- Connector metering or freeway-to-freeway connector metering implemented to regulate high traffic volumes from one freeway to another. The connector metering concept is similar to that of ramp metering. However, because of the high speeds and heavy volumes on the connectors, longer queuing storage and advance warning devices are required. Connector metering should not be implemented at locations with inadequate storage capacities and insufficient sight distances. Freeway-to-freeway ramp metering has been implemented in a

number of areas around Los Angeles, CA; Seattle, WA; Minneapolis, MN; and Portland, OR.[4]

Ramp management strategies can be implemented to address recurrent and nonrecurrent congestion.

Figure 3. Ramp Metering[4]

Ramp metering strategies can provide local (isolated) or systemwide (coordinated) control. Some of the algorithms that were developed for systemwide strategies can also be used for local ramp metering control. Local control selects metering rates to address congestion or safety problems at a specific on-ramp merge area. This strategy is normally applied where the congestion problem is isolated. Systemwide control selects metering rates on a number of on-ramp locations in a coordinated manner based on the conditions along a freeway segment, an entire corridor, or even a network of corridors. The traffic conditions at other locations in the system are considered when determining metering rates for a specific ramp.

Another differentiation of ramp metering strategies is related to how they are applied. Pretimed, also referred to as time-of-day or fixed-time control, uses metering rates calculated offline based on historical conditions and applied at a fixed schedule by time of day and day of the week. With traffic-responsive and adaptive control, traffic parameters measured in real time are used as inputs to ramp metering algorithms to determine the metering rates, and in some cases when and where to activate ramp metering. Pretimed, traffic-responsive, and traffic-adaptive control can be applied locally or systemwide. In some ramp metering implementations, TMC operators are allowed to select or modify automatically generated ramp metering rates based on their assessment of traffic conditions.

Pretimed control does not require detection devices or communication with a TMC and requires only a simple hardware and software configuration. Although this type of control is easier and costs less to implement and maintain compared to traffic-responsive control, it does not adequately accommodate the variability of transportation system conditions. Pretimed control has been applied in situations where the infrastructure required for traffic-responsive ramp metering is not available and as a backup to traffic-responsive control, in case of detector or communication failures. Traffic-responsive and

-adaptive control requires traffic detectors, a communication subsystem, and additional local and central software and hardware and is more expensive to implement and maintain. However, it can produce better operations by adapting to varying traffic conditions. As with pretimed ramp metering control, traffic-responsive ramp metering can be applied at the local and systemwide levels. A difference between local and systemwide control is that the latter requires data from detectors at multiple locations at ramps downstream and/or upstream of the ramp for which the ramp metering rate is calculated.

Successful implementation and operation of ramp metering requires that a number of issues be considered. Ramp management strategies may adversely affect or may be perceived to adversely affect on-ramp traffic, other facilities in the region, or other specific traveler groups. One of the issues that has been raised is that of equity, in that ramp metering strategies appear to favor longer suburban trips over trips generated from zones closer to the centers of urban areas. Complaints from the general public, neighborhood groups, and local businesses have to be addressed at the implementation and operation stages of ramp metering. Another issue is the potential impact of ramp metering on other facilities as a result of diversion of traffic from freeways to surface streets and queue spillback from on-ramps onto other freeways and/or surface streets. Thus, there is a need to balance the performance of the freeway corridor to achieve maximum benefit. In addition, ramp metering strategies should include detection and management strategies for metered ramp queues to prevent excessive queues and spillbacks from these ramps to adjacent streets. Microscopic simulation modeling has been successfully used to assess the impacts of different ramp metering algorithms and strategies and can be used as an effective tool in the selection of a ramp metering strategy and parameters.

Socioeconomic considerations and equity issues associated with ramp metering must be adequately addressed. This step should involve public information and outreach efforts to explain the reasons for and benefits of the ramp metering implementation. Ramp metering also requires coordination with transportation agencies responsible for managing other affected transportation facilities in the region.

Preferential treatment for specific vehicle classes, such as high-occupancy vehicles (HOVs), transit vehicles, trucks, and emergency vehicles, can be used to allow bypassing of single-occupant vehicles queues at ramp entrances. Exclusive HOV ramps and ramps dedicated to the sole use of construction, delivery, or emergency vehicles have also been implemented.

Studies have evaluated the performance of corridors with and without ramp metering. A large deployment of ramp metering is operated by the Minnesota Department of Transportation in the Twin Cities metropolitan region with over 430 ramp meters. The Twin Cities ramp metering system was subjected to an extensive evaluation during which the ramp meters were turned off for a six-week period for evaluation of the impacts.[5] Several performance measures were used to evaluate the ramp metering system. Below is a summary of the results:

- Throughput: Traffic volumes on the freeway mainline were observed to decrease by 9 percent when the meters were shut down. The volumes on the parallel arterials did not appreciably change when the meters were shut down.
- Travel Time: Freeway speeds were reduced by 14 percent, or 7.4 miles per hour (mph), when the meters were shut down, resulting in greater travel times that more than offset the elimination of ramp queue delays. The travel times on the parallel arterials did not appreciably change when the meters were shut down.
- Travel Time Reliability: Travel times were nearly twice as unpredictable when the meters were shut down.
- Safety: Crashes on freeways and ramp segments increased by 26 percent when the meters were shut down.
- Benefit/Cost Analysis: The ramp metering system was estimated to produce approximately $40 million in benefits to the Twin Cities region. These benefits outweighed the costs of the ramp metering system by a ratio of 15 to 1.

A study of the benefits of ramp metering in Washington State reported the following benefits:[6]

- Over 30 percent reduction in rear-end and sideswipe collisions.
- An 8.2 percent reduction in freeway mainline congestion.

The above results indicate that significant improvements in the mobility, reliability, and safety of the transportation systems can be expected from effective implementation of ramp metering.

The FHWA created a video, “Ramp Metering: Signal for Success,” that provides a basic introduction to ramp metering. The video is intended for local decision-makers and the public, and features testimonials from officials of several cities. The benefits of ramp metering and the importance of developing a public awareness program are emphasized. (See www.youtube.com/watch?v=rsvaGXW6moA.)

Information Dissemination

Providing information to travelers is one of the most widely used management strategies. Infrastructure devices that disseminate information, such as dynamic message signs (DMS) and highway advisory radios (HARs), are classified by the NITSA as traffic management systems rather than as advanced traveler information systems. This classification is because these devices are generally operated by public or toll agencies for traffic management purposes rather than by information service providers for the sole purpose of providing information to travelers. Other types of traveler information technologies that are not classified as TMS devices by the NITSA, such as 511 traveler information phone systems, websites, kiosks, phone apps, and in-vehicle navigation systems, are not discussed in this module. Such technologies are discussed in Module 4, “Traffic Operations.” Furthermore, although information dissemination is discussed under freeway management in this module, it is also applicable to other management systems, such as arterial and transit management systems.

Dynamic message signs support TMS objectives by affecting traveler decisions, such as diverting to alternative routes during incidents, and thus reducing additional incidents. As applied to traffic management, DMS and HAR are part of the ATMS06 (Information Dissemination) NITSA service package. When they are used in transit management, they are part of APTS08 (Transit Travel Information). Applications of DMS have also been proposed for multimodal dissemination of information with the goal of shifting the mode of travel in the case of highway or transit incidents, special events, and emergencies. DMS have also been referred to as variable message signs (VMS) and changeable message signs (CMS). The details of DMS and HAR technologies are presented in Module 9. This section discusses their use as part of TMS.

Figure 4. Dynamic Message Signs

Source: Courtesy of Jeffrey Katz, Florida DOT.

In general, DMS and HAR are used as part of TMS to encourage some type of response from motorists to improve system performance. The desired responses could be to reduce speed, move out of a blocked or closed lane, or take an alternative highway route or transit option.[7] The disseminated information at highway locations can include travel advisories and warnings of nonrecurrent events, such as incidents, construction, transit delays, queue warning, adverse weather conditions, and special events; travel time; dynamic speed limit; lane control; dynamic pricing of managed lanes; and alternative routes, modes, or transit lines. These signs are also used for AMBER Alert and Silver Alert messages. An AMBER Alert is an alert issued upon the suspected abduction of a child. A Silver Alert is a broadcast of information about missing persons, especially seniors with mental impairments, to aid in their return. DMS are also used at transit stations to provide information about transit vehicle arrivals and expected delays.

A number of challenges are associated with DMS deployment. Transit authorities need to develop operational policy to guide message development and posting. This policy should be based on identified needs and requirements that can be traced to the TMS concept of operations. The policy should cover who is allowed to post messages, the types of messages, the conditions that warrant message posting, the locations of these postings under different conditions, and so on. Information dissemination devices should be located and operated to reach the maximum percentage of the motorists targeted by the dissemination efforts. The locations must allow sufficient time for these motorists to take the desired actions. Some candidate locations are upstream of major decision points, bottlenecks, and high incident areas, and where providing weather information is important.[7,8]

DMS with poorly designed messages, complex messages, or messages that are too long for motorists to read at prevailing highway speeds can lead to motorist confusion and can adversely affect traffic flow and the transportation agency's credibility.[7] Thus, it is important that agencies ensure that the content, format, and application of information are of high quality, consistent, and timely.

An important decision that needs to be made at the TMC is to determine if and when a given device or group of devices within the overall system should be activated to address a particular situation or problem and when these devices should be deactivated. The decision process can be automated based on the event location and type, can be manual with TMC operators deciding which DMS to activate, or a hybrid of the two approaches. In the combined approach, the central software recommends to TMC operators which device to activate, but the operators make the final decision. DMS can also be installed on-board transit vehicles to provide trip information to travelers.

Another related device for disseminating travel information is the graphical information board, which is normally installed at selected locations where a large number of travelers are expected to view it. These locations include malls, office buildings, and highway rest areas. Trailblazer signs can also be used to provide motorists who are rerouted around incidents with real-time information after they divert to alternative routes. The signs guide motorists along the alternative routes and direct them back to their original routes downstream of the incident location. Trailblazer signs can be static, dynamic, or static with flashing beacons.

Several researchers have conducted surveys using the “stated preference” approach to determine the expected percentages of travelers diverted as a result of DMS. The studies concluded that DMS advising travelers of congestion ahead—with no additional information concerning expected delay times or possible alternate routes—can cause up to 60 percent of the freeway traffic to exit the freeway ahead of the bottleneck.[9] However, actual observation of diverted traffic found significantly lower diversion rates. For example, in Long Island, NY, an evaluation of the INFORM ATMS project indicated much lower traffic diversion rates compared to the stated preference survey, with 5 to 12 percent of mainline traffic diverting to alternate routes in typical incident conditions.[10] Several European field studies have found that the diversion rates range between 27 and 44 percent.[11]

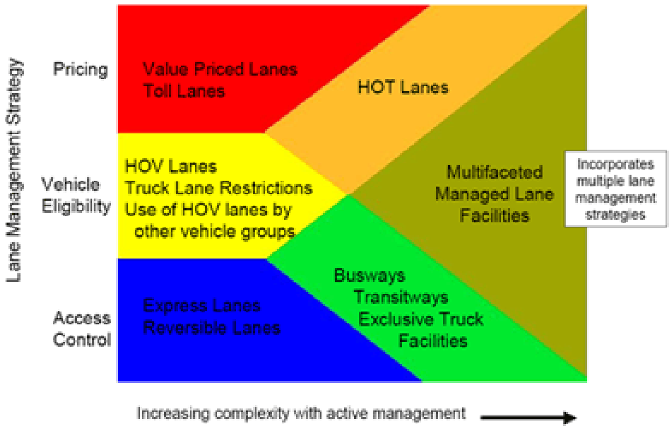
Managed Lanes

Interest in managed lane strategies has increased significantly in recent years. Managed lanes are defined as "designated lanes or roadways within highway rights-of-way where the flow of traffic is managed by restricting vehicle eligibility, limiting facility access, or and in some cases collecting variably priced tolls."[12] The term *managed lanes* refers to special-use lanes such as HOV lanes, high-occupancy toll (HOT) lanes, express toll lanes (ETLs), truck-only toll (TOT) lanes, bus-only lanes, and other special use lanes.

With managed lanes, a subset of the lanes within a freeway cross-subsection is separated from the general-purpose lanes for use by specific types of vehicles, vehicle ridership, and/or paying travelers. The operation of and demand on the facility is managed to continuously achieve preset operation standards such as speeds close to free-flow speeds or a given level of service based on the density of the managed lanes. Pricing may also generate revenue for transportation agencies.

Figure 5 shows a view of managed lane applications. In the figure, three lane management strategies are used together to manage traffic: pricing, vehicle eligibility, and access control.

Figure 5. Managed Lane Applications[13]



Pricing strategies involve charging subgroups of motorists a toll for travel and is normally variable, with higher prices charged during congested periods. Pricing is implemented to actively manage congestion. However, it also generates revenue for transportation agencies that can be used to improve or maintain the transportation system. Pricing of managed lanes can be on a fixed-schedule basis and varied by time of day or day of week. Increasingly, however, agencies are implementing dynamic pricing strategies that change the toll rate based on real-time measurements of traffic congestion on the managed lane and/or general purpose lane.

The second strategy is vehicle eligibility that involves selecting the types of vehicles allowed on the managed lanes, either for free or for a toll. A commonly considered alternative is to allow higher-occupancy vehicles such as transit vehicles and HOVs (in some cases only preregistered vehicles with a specified minimum number of occupants) use the lanes for free or at a discounted rate, while charging all other vehicles the full toll. TMS can vary vehicle eligibility by time of day and day of week, if found to be beneficial.

Establishing access control to managed lanes is a third important strategy to manage the operations. The access points to the managed lane should be determined as part of the planning, traffic and simulation analyses, and design processes. Traffic analyses, for example, may indicate that the access to managed lanes should be limited to very few points to minimize the turbulence due to weaving maneuvers. In some cases, preferential treatment can be given at specific access points for a subset of a vehicle class, for example, to allow only emergency and transit vehicles to use some access points.

An important factor in the success of a managed lane project is the selection of the best lane management strategies based on the objectives of the project, taking into consideration existing and forecast demands, capacity, traffic operations, and environmental and societal concerns. In addition, the strategy should include establishing an acceptable level of performance of the managed lanes. The level of performance could be based on volume, speed, and/or traffic density. Managed lane pricing should be varied to maintain this level of performance.

Depending on the specific application, managed lanes require the participation of several agencies, including transportation planning agencies, State departments of transportation, transit agencies, regional transportation authorities, toll agencies, law enforcement agencies, and other stakeholders. These lanes frequently cross jurisdictional boundaries. Thus, a successful managed lane project requires the cooperative efforts of various agencies starting from the initial planning stage and continuing through the operational stage.

Another important strategy is for transportation agencies to communicate the benefits of the managed lane project through public outreach activities. Communication is particularly important to reducing any initial opposition to the tolls that will be charged for the use of managed lanes. Because electronic toll collection (ETC) technology is needed to pay tolls for some managed lane applications, motorists should be informed that their vehicles must be equipped with an ETC transponder in order to use the facility. If paying based on license plate readers is allowed, this also should be communicated to the motorist. Other information that should be communicated includes the toll rate strategy, ingress and egress locations, occupancy requirements, and operating hours.[14] During operation, DMS should be used to alert motorists about the current toll rates and any changes to the operations of the managed lanes.

Enforcement is another important element of a managed lane implementation and should be considered early in the project development. Without proper enforcement, high violation rates can be expected. Automated enforcement based on license plate readers has been used to support the enforcement task; however, legal and technical challenges are associated with another parameter for enforcement, which is the required verification of vehicle occupancy. Enabling legislation may be necessary to allow this parameter to be measured, considering potential privacy concerns.[14]

As agencies increasingly consider managed lane implementation, interest in the modeling of managed lanes has grown significantly. Advanced modeling techniques—such as behavioral surveys and models, dynamic traffic assignment, and mesoscopic and microscopic simulation—will increasingly be used to analyze traffic conditions, strategy alternatives, and revenue generation of managed lanes.
Detailed discussions of the issues associated with managed lane implementation and operation can be found in references 12 to 14. Also, an informational video about the Florida Department of Transportation’s I-95 Express Project describes how the project combines the four transportation management techniques of transit, tolling, technology, and travel-demand management to improve the travel time reliability and reduce congestion on I-95 in Miami-Dade County. The video can be found at www.youtube.com/watch?v=U1VzpFcfU78.

Active Traffic Management

Active traffic management (ATM) systems involve the use of strategies, tools, and resources to dynamically manage, control, and influence traffic flow of transportation facilities such as roads, freeways, designated lanes, and ramps. ATM strategies are implemented in response to prevailing conditions, possibly in combination with the prediction of conditions, for example, to prevent or delay breakdowns, improve safety, promote sustainable travel modes, reduce emissions, or maximize system efficiency.[15] As defined here, ATM includes many of the technologies and strategies discussed elsewhere in this module and in Module 4, such as travel time and alternative route signing, adaptive signal control, adaptive ramp metering, weather-responsive management, and integrated corridor management strategies.

In Northern Virginia, a $32 million project for an active traffic management system that extends along I-66 from the Washington, DC, line to Haymarket, VA, includes new overhead sign gantries, electronic shoulder and lane controls, speed displays, incident and queue detection, and increased traffic camera coverage. A video from a citizen information meeting on July 28, 2011, is available (www.youtube.com/watch?feature=player_embedded&v=cf__pmSIR6s#!).

Speed Harmonization and Variable Speed Limits

Static speed limits are set to ensure safety during normal conditions, but they do not consider nonrecurrent events such as adverse weather, incidents, or work zones. Use of variable speed limits (VSLs), also known as speed harmonization, has been proposed to improve safety during these conditions. In addition to the safety applications, VSLs have been proposed for use upstream of congestion as a way to limit the progression of a congestion shockwave upstream of bottlenecks and thus improve mobility. Real-world evaluations have been conducted on the safety impacts of VSLs. However, the mobility impacts have been evaluated using mostly simulation. Most of the real-world VSL implementation has been to improve safety in bad weather or other reduced-visibility conditions. A recent review of the use of VSLs discusses several safety applications in the United States and Europe.[16] The success of speed harmonization requires that travelers accept and understand the reasons behind changing the speed limit and the associated benefits. The evaluations of effectiveness to date have shown mixed results. In some cases, the VSL implementations were not effective because the visibility sensors used were not reliable or vehicles were not complying with the reduced speed limits.[16] However, in other cases, VSL implementations were effective. Enforcement was found to be an important component of successful application. In some European implementations, the enforcement is automated, which has been effective in increasing compliance. Changes in legislation may be required to effectively enforce VSLs in the United States. In effective implementations, VSLs have been able to decrease traffic speeds in adverse conditions (by 5 to 7 mph) and have improved safety by reducing the frequency and severity of weather-related crashes.[16]

Dynamic Lane Assignment

Dynamic lane assignment (DLA) refers to the use of lane control signals to inform motorists of changes in lane conditions due to events such as incidents, maintenance, construction, and weather events and to advise them to start changing lanes well in advance of the lane closure. Lane control displays have also been used for reversible lane systems and for active lane reassignment at intersections. Lane control signs are often installed in conjunction on the same overhead structures as those used for variable speed limit signs. As with speed control, the European installations have ensured that at least one lane control display is visible at all times to motorists, resulting in overhead structure spacing every 1,600 to 3,300 feet.[16]

Typically, lane control signs indicate lane closures by showing a red “X” above the lane. Sometimes, advance notice to motorists to switch lanes is also given using a diagonal arrow pointing to an adjacent lane. On the M42 motorway in the United Kingdom, lane and speed controls are accomplished by activating signs at four overhead structures upstream from the closure. The first indicates a reduction in speed limit. The second indicates a further reduction in speed. The remaining two locations use diagonal arrows to get the drivers to change lanes. Examples of dynamic lane control in the United States include systems in Minneapolis, MN; Seattle, WA; I-66 in Northern Virginia; and Dallas, TX.

Hard Shoulder Running and Bus-on-Shoulder

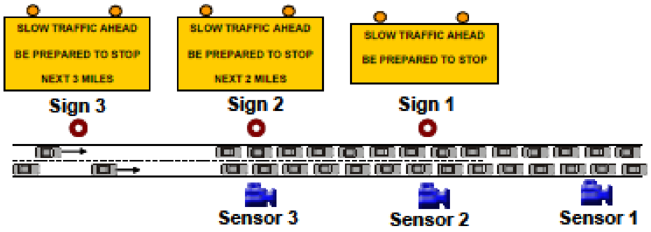
Hard shoulder running, also referred to as temporary shoulder use, is used to add temporary road capacity during recurrent and/or nonrecurrent congestion conditions. A number of examples of existing implementations of this strategy can be found in Europe, including in Germany, the Netherlands, and the United Kingdom. It has been reported that the bottleneck throughput can be increased by 7 to 20 percent.[16] This increase in throughput is of course a function of the capacity of the bottleneck without the strategy. An important consideration of hard shoulder running is that the operation must extend beyond the bottleneck location; otherwise, it will result in increasing congestion by feeding more traffic to the bottleneck location. Hard shoulder running is typically implemented in conjunction with other active management strategies such as variable speed limits and lane controls.

In some cities in the United States and Canada, buses are allowed to drive on the shoulder. This is usually referred to as a bus-only shoulder lane. Instead of having full operation of buses on the shoulders, a cost-effective potential application is to allow buses to use shoulders as bypass lanes or queue jumper lanes to bypass congestion at a traffic bottleneck. The bus use of shoulders has been implemented in California, Maryland, Minnesota, Ohio, Virginia, Washington, British Columbia, and Ontario. A review of these implementations and the lessons learned can be found in a report by the Transit Cooperative Research Program (TCRP).[17] National experience indicates time savings of 5 to 15 minutes with the use of freeway shoulder lanes, for the average trip, depending on the level of congestion.

Queue Warning

Slow or stopped traffic on freeways is a major cause of crashes. In addition, vehicles competing for gaps to change lanes close to the back of the queue contribute to additional disturbance in the traffic stream. Queue warning is an active management strategy that has been used to warn motorists of downstream queues and to direct through traffic to allow alternate vehicles to merge from closing lanes. The goal is to effectively use available roadway capacity and reduce the likelihood of crashes due to queuing.[16,18] The desired effect of this strategy is that motorists take appropriate actions, such as slowing down or changing lanes. Queue warning can be supported by the use of VSL to emphasize the need to reduce speed. An example of a queue warning system setup is shown in Figure 6.[19]

Figure 6. Example of Queue Warning System Setup[19]



Arterial Systems

This section discusses strategies and technologies that are specific to the management of urban arterial streets. Other technologies and strategies that support arterial management are presented in other sections of this module and in Module 4. Examples of these other technologies and strategies include DMS, active traffic management, TMCs, data archiving, performance measurement, incident management, and smart work zones. As with other TMS, there should be links between arterial systems' operational goals, objectives, strategies, and tactics and the steps of the short- and long-range planning process.

Traffic Signal Systems

Traffic signal operation is one of the most visible services provided by transportation agencies to the traveling public. Traffic signals have significant impacts on the mobility, reliability, fuel consumption, and environmental impacts of the transportation system. Thus, it is critical to implement effective traffic signal operations and management processes. These processes involve the planning, design, operation, integration, maintenance, and administration of a traffic signal system to optimize the efficiency, mobility, safety, and reliability of the arterial roadway network. Signal control is included in ATMS03 in the NITSA.

In 2012, the National Transportation Operations Coalition surveyed the quality of traffic signal operations in the United States. The average score given by the survey was a D+ on a scale of A to F, in terms of the overall quality of traffic signal operation. The 2012 grade of D+ is a slight improvement over grades of a D− in 2005 and a D in 2007. The main reasons for the low scores are that the signals generally are not operating as an efficient, well-integrated system; proactive management is limited; and resources are not well spent. However, the continuing, slow improvement in the national score shows some progress by agencies that operate the majority of traffic signals in the United States. The scoring results also indicated that medium and large agencies operating more than 150 traffic signals scored an average grade of C on a national basis, which is better than the overall average of D+.[20]

Signal System Components

The basic types of traffic signal control include pretimed, semiactuated, and fully actuated control. Pretimed control consists of a series of intervals that are of fixed duration. This type of control is adequate for closely spaced intersections in downtown areas where traffic volumes and patterns are consistent from day to day. Actuated control consists of intervals that are activated and extended based on demand presence as measured by vehicle detectors. Fully actuated control is used for isolated intersections to accommodate the variability of traffic patterns. Semiactuated control uses detection only for the cross-street and left-turn movements at an intersection, whereas the phases associated with the main street through movements are operated as nonactuated. Semiactuated control is generally applied at intersections that are part of a coordinated signal system.

The type of signal control (pretimed, actuated, or coordinated semiactuated) at a given intersection influences the design of system components. In general, the basic components of signal control systems include a signal controller and cabinet, signal heads and associated infrastructure, a detection subsystem (for actuated and semiactuated), central hardware and software, and a communication subsystem. Implementing other advanced strategies, such as traffic-adaptive, preemption, and priority, as discussed later in this module, can also affect the selection of signal system components. The quality of intersection operation requires careful consideration of the relationship between the detection system design and the signal controller settings. The central software and hardware and traffic management center operations play a key role in the success of signal control. Thus, complete understanding of signal control requirements is needed prior to starting the design process of system components.

Traffic Signal Timing

Poor traffic signal timing is one of the major causes of traffic delays in urban arterials. Thus, traffic signal monitoring and retiming is one of the most cost-effective strategies to improve arterial system performance. Retiming should be based on identified needs such as substantive changes in traffic patterns, long or excessive delays, and safety concerns. The recommended schedule for retiming traffic signals has been every three to five years.[21] Basic signal timing parameters that need to be selected include the cycle length, green split, offset, phase sequence, left- and right-turn protections and permissions, pedestrian phase design, and clearance intervals. Existing signal optimization software, possibly combined with microscopic simulation, can help in this effort. However, field fine-tuning of the resulting timing is often necessary.

Coordination of signals provides additional benefits compared to optimizing the operation of isolated signals. Such coordination reduces the interruptions to traffic platoons along major streets. A number of methods have been developed to determine if coordination between adjacent signals is beneficial.[22] The benefits are expected to be higher when the signals are close to each other and when there are increased traffic volumes between the intersections.

The primary goal of traffic signal timing is to maintain the safe and efficient operation of the controlled intersections, considering local, regional, State, and Federal policies. A context-sensitive approach should be applied to signal timing to carefully consider the controlled intersection environment, the local policies, and the unintended consequences of signal timing changes.

Transportation agencies have to continuously monitor the operations of their signals and make adjustments when a change in the traffic patterns or geometric conditions is detected. This response can include making minor adjustments to the detector settings and fine-tuning signal timing parameters or completely retiming the signals. Central software tools should be used to report performance metrics such as green time utilization, green band utilization, and arrivals on green, allowing agencies to constantly monitor their systems and use the data as a basis to modify the parameters of their systems. Proactive monitoring of signal timing operations and maintenance should include establishing signal timing policy for regular timing updates, field inspections, continual maintenance of signal systems, and communication to identify issues with signal timing and associated solutions as soon as possible.[21] Operational objectives will need to be established and used to drive these processes.

A challenge of signal timing tasks is the difficulty transportation engineers face in assessing the performance of existing systems because of the lack of sufficient data collection and analysis. Many agencies have not built performance measurement into their systems, although this can be done using current software and hardware technologies. The reason for this gap is that the agency has to be committed to performance measurement and to devote the resources needed to acquire and maintain the necessary detection system. In addition, signal timing optimization requires resources for data collection, experience with optimization models, familiarity with hardware and software, and knowledge of field operations. Some agencies have limited resources to develop new signal timing plans. The Texas A&M Transportation Institute, in a study for the FHWA, proposes cost-effective techniques that can be used to generate good signal timing plans to be used by those agencies.[19]

In 2001, Skabardonis presented the findings from an analysis of the impacts of signal control improvements based on a large number of real-world implemented projects.[23] The average measured savings for coordinated systems were 7.4 percent reduction in travel time, 16.5 percent reduction in delay, and 17 percent reduction in stops. These measured benefits are generally in agreement with the model estimates.

Programs are under way to study coordinating traffic signals as one of the most cost-effective approaches to improve traffic mobility. A four-minute video (www.marc.org/transportation/ogl/video.htm) explains how 20 cities, two states, the Mid-America Regional Council, and the FHWA are working to improve system performance flow in Greater Kansas City. In addition, the Southwestern Pennsylvania Commission has developed a regional traffic signal program. This program has produced before and after videos of signal retiming (they can be found at www.spcregion.org/trans_ops_traff_vids.shtml).

Advanced Signal Control Strategies

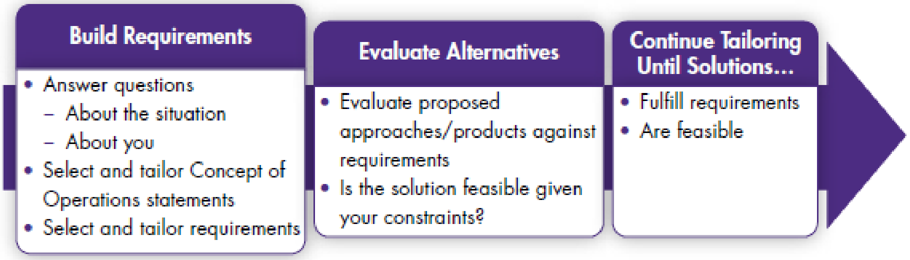
Traffic signal timing plans derived as described in the previous section are commonly applied at a fixed schedule by time of day and day of the week. The timing parameters and plan activation schedules are set based on historical traffic demands and field observations. However, these timing plans may not be able to adequately account for the variations in traffic demand patterns between days.

To better account for the variability of traffic demands between days, traffic-responsive system (TRS) strategies have been proposed for implementation since the 1970s. Typically, TRS uses traffic volume and/or occupancy measurements from a few system detectors to select the signal timing plan to be activated from a library of plans instead of selecting the plans based on time of day. A number of issues with TRS have limited its use. TRS is meant to adjust the timing plans to meet varying traffic conditions. However, TRS selects a timing plan from a library of plans based on historical data. Thus, new patterns not accounted for in these plans cannot be accommodated by the TRS. In addition, the transition between plans has negative impacts on the coordinated operation during the transition period. Thus, the number of transitions should be limited to avoid the negative impact. TRS is also inherently slow to respond to changes in traffic conditions.

For these reasons, adaptive signal control technologies (ASCTs) have been implemented since the early 1980s and have been increasingly considered by transportation agencies in recent years for critical corridors or subnetworks. An ASCT system continuously adjusts, in real time, signal timing parameters based on current traffic conditions. Several ASCT products exist that vary in the algorithms used, detection requirements, and the flexibility in responding to changing traffic demands. The deployment of adaptive signal control systems remains limited in the United States due to agency concerns about cost, installation, and operation requirements; complexity; uncertainty associated with the benefits of these systems; detection requirements; the need for hardware and software upgrades; and the need for additional staff training.[24] However, new systems have been developed and are expected to be developed that account for some of these concerns

The FHWA has started the Every Day Counts ASCT Initiative to mainstream the use of adaptive signal control technology. The goal is that in cases where traffic conditions, agency needs, resources, and capability warrant the use of ASCT, it should be implemented. The FHWA has produced the “Model Systems Engineering Documents for Adaptive Signal Control Technology Systems—Guidance Document”[25] to assist agencies when making decisions regarding ASCT implementation, to reduce the level of effort and address the risks associated with procurement of ASCT. The guidance recommends that agencies considering deploying an adaptive signal control system produce system engineering documents that provide justification and establish the foundation for the deployment. These documents include the concept of operations, system requirements, verification plan, validation plan, and procurement plan. Figure 7 presents an overview of systems engineering for ASCT definition.

Figure 7. Overview of Systems Engineering for ASCT Definition[25]



Past evaluations indicate that adaptive signal control could reduce travel time by 5 to 7 percent during the morning and evening peak periods and 10 to 12 percent during midday and weekend periods over typical time-of-day plans, provided that the system is not oversaturated.[26] Although there is agreement that ASCT deployment does not solve oversaturated traffic conditions caused by capacity constraints, it may be able in certain conditions to delay the start of oversaturation and reduce its duration.

Santa Clara County implemented an adaptive signal control that considers pedestrians and uses pedestrian sensors. A video about the project can be found at www.youtube.com/watch?v=doXpCB3_nDA.

Traffic Signal Preemption at Railroad Crossings

Preemption is normally implemented at railroad crossings and drawbridges, and to give the high-priority classes of vehicles (such as trains, boats, emergency vehicles) the right-of-way as they approach traffic signals. Arterial traffic management systems typically allow different preemption schedules to be programmed into traffic controllers, each with a priority level, for example, to give railroad preemption higher priority than emergency vehicle preemption.

Traffic signal preemption near highway–rail grade intersections is necessary to avoid crashes between trains and automobiles. Traffic signals are preempted if it is expected that the queue from the signalized intersection has the potential for extending across a nearby rail crossing due to the signal operations. Preemption should also be considered when traffic from the railroad crossing could spill back to adjacent intersections.[27] Preemption can give motorists an opportunity to clear the crossings before a train arrives. The FHWA *Manual on Uniform Traffic Control Devices* requires the preemption of all signals located within 200 feet of the crossing.[28] However, many agencies reported that it is often necessary to apply preemption well beyond the recommended 200-foot distance, pointing out the need for a detailed queuing analysis rather than a specified distance.[29]

A number of ITS technologies have been proposed or used to support railroad crossings. Three related service packages have been included in the NITSA addressing different levels of ITS implementations to railroad crossings (ATMS13, ATMS14, and ATMS15). Queue detectors located downstream from the tracks on the approach to the traffic signal can be used to allow the activation of the preemption sequence when a queue is detected. Another possible strategy is for the crossing equipment to notify an approaching train of any failure in crossing operations or vehicles stopping on tracks and for the train detection system to notify the controller of failures in the detection. Advanced detection technologies or train tracking technologies can be used to notify the controller of more accurate time of train arrival. Center-to-center communication between highway and railroad agencies can be implemented to exchange information between agencies about incidents, failures, special events, and maintenance activities. In addition, information about approaching trains and related incidents can be sent to DMS located in advance of the crossing and to travel information service providers.

Implementing advanced strategies at railroad crossings is complicated by the fact that coordination between two or more highway and rail agencies is required. An agency survey[29] indicated the importance that the survey responders put on improving coordination efforts between the rail operation and the highway agency in activities such as design, implementation, and maintenance.

Emergency Vehicle Preemption (EVP) and Routing

Preemption control is also used to give priority to emergency vehicles (mainly fire engines and emergency medical services) responding to emergencies. The objectives of emergency vehicle preemption (EVP) are to reduce emergency response time, improve safety and stress levels of emergency vehicle personnel, and reduce crashes involving emergency vehicles at intersections. The reduction in the response time is expected to reduce traffic incident duration and thus congestion, the probability of death during incidents, and the severity of fire. This service is classified as an emergency management service in the NITSA and is covered by EM02.

A number of technologies have been used for EVP, including radio-, GPS-, light-, infrared-, and sound-based technologies. The preemption can be activated either by the local controllers or by the central system. Decisions need to be made regarding the supporting technology and configuration of the EVP implementation based on careful identification of project requirements. Some cities have installed EVP preemption equipment on 100 percent of their signals. Others installed EVP equipment only along frequently used paths of emergency vehicles, at intersections with identified problems, or on newly installed signals.[30] Many agencies limit EVP to fire and rescue trucks.

Since EVP can involve several highway and emergency management agencies, these agencies should be involved in the identification of system requirements and work together to ensure effective planning, deployment, and operation of EVP systems. A main consideration in the selection of the supporting technology and products is the interoperability with stakeholders' systems in the local area and possibly neighboring jurisdictions. Because EVP and transit signal priority (TSP) can use the same supporting technologies, the EVP implementation should consider the current or future TSP to reduce the cost and complexity of the implementation. Another issue that should be considered is the ability of the implemented EVP system to handle multiple conflicting priority calls. This capability is important because the emergency vehicle operators assume that they will get the right-of-way when approaching the signal, and they are not aware of the existence of conflicting requests.

Unlike the railroad crossing preemption described earlier, the vehicle and pedestrian minimum green and clearance intervals are not cut short, so EVP is not guaranteed immediately for an approaching emergency vehicle. Therefore, emergency vehicle drivers need to be prepared to stop if provision of green is delayed. These drivers should be trained on EVP operations and limitations.

Another strategy is the routing of emergency vehicles, either alone or in combination, with traffic signal preemption. This can involve the identification of static routes offline using shortest path assignment techniques and/or dynamic routing of emergency vehicles in real time, taking into consideration real-time traffic information. The real-time applications may calculate the best route at the start of the trip or dynamically recalculate the best route from the vehicle's location to the destination as the emergency vehicle progresses through the network, taking into consideration the changing congestion level. The routes can be calculated automatically by the dispatching software, possibly allowing the verification of the suggested routes by the dispatchers.
In defining service needs of fire and rescue agencies, jurisdictions consider fire flashover times and survival rates for cardiac patients along with local conditions, including development density and loss potential. Emergency vehicle preemption can lead to improvements in emergency vehicle safety and response times, thereby increasing the effective service radius of a single station.

Transit Signal Priority (TSP)

One of the widely investigated management strategies on urban streets has been preferential treatments of transit vehicles. These preferential treatments have been justified by the fact that a bus can carry significantly more passengers than a passenger car. Thus, treatments that favor buses are expected to reduce the total person-hours of travel and encourage mode shift to transit. Preferential treatments of transit vehicles have included bus lanes, queue jumpers, and transit signal priority (TSP).

TSP is an operational strategy that aims at providing priority to transit vehicles at signalized intersections by extending the green or shortening the red to reduce the transit time of these vehicles. The goal is to improve travel time and reliability, increase total person throughput of the system, and increase the attractiveness of transit vehicles with minimal impacts to normal traffic operations.

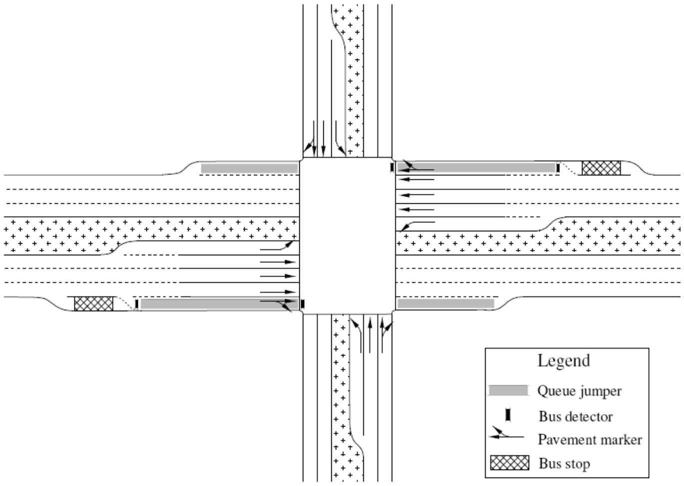
Although preemption and priority strategies may use similar equipment, the two strategies are different. Signal priority modifies the normal signal operation to accommodate transit vehicles, whereas preemption interrupts the operation, as described in the previous section. Careful attention should be given to minimizing the impact on general traffic operations.

TSP provides preferential treatment of transit vehicles over other vehicle classes at a signalized intersection without causing the traffic signal controllers to drop from coordinated operations. TSP can be implemented in a variety of approaches, including early green (red truncation), green extension, phase insertion, phase rotation, and passive priority.[31] A green extension strategy extends the green time when a transit vehicle approaches the signal on green. An early green strategy, also referred to as red truncation, shortens the green times of the conflicting phases for faster return to green to serve the transit vehicles for which priority is to be given. Phase insertion involves actuated transit phases that are displayed only when a transit vehicle is detected. An example is the provision of a protected left-turn phase only for transit vehicles. Another strategy is phase rotation, which can be implemented to affect the signal phase sequence when a transit vehicle is detected. This, for example, could include the switching of a lead-lag left-turn sequence to a lag-lead sequence.

The TSP strategies described above can be classified as active priority strategies. Passive priority strategies do not require hardware and software modifications. Passive priority is applied based on knowledge of transit route, schedule, dwell time, and ridership without detecting transit vehicles as they approach the intersection. One such passive priority strategy is establishing signal progression for transit vehicles.

A queue jumper is a preferential bus treatment that combines a short stretch of a special lane with a TSP to allow buses to bypass waiting queues of traffic and then to cut out in front of the queue by getting an early green signal (see Figure 8). Several jurisdictions have also implemented bus lanes that are provided exclusively for the use of buses, where bus transit demand justifies their use.

Figure 8. Example Configuration of a Queue Jumper



Source: Florida International University.

Issues similar to those discussed for emergency vehicle preemption are associated with bus priority and other preferential bus treatment. As with preemption, a systematic approach with multiagency involvement is needed for the planning, design, implementation, operations, maintenance, and evaluation of TSP.

Experience from prior implementations indicates a bus travel time reduction of about 15 percent, depending on the exiting signal delay, with minor impacts on the overall intersection operations. Most of the evaluation studies of transit preferential treatments have been performed using simulation analyses, although few field evaluation studies exist.

Parking Guidance Information Systems

Parking guidance information (PGI) systems provide parking availability information to drivers. These systems monitor the supply and demand of parking spaces and provide motorists with directions to available parking spaces. The result is a more efficient use of parking space, reduced delay in the time spent searching for parking, and reduced delays to the surrounding transportation network.

Parking availability information is typically presented as a status, such as “Full,” “___ Spaces Available,” “Closed,” and “Almost Full.” Additional information that may be provided includes the type of parking facility, directional arrows, regulatory information, and operation information.

PGI systems can be for a single facility (addressed by ATMS16 service package in the National ITS Architecture) or areawide (ATMS17). PGI systems require equipment that detects the number of vehicles entering and exiting the parking facility or area and, in some designs, individual aisles or even spaces. Vehicle detection could be made using a detection technology such as inductive loops or a nonintrusive vehicle detection technology. Vehicle counts could also be obtained by counting the parking facility gate openings or the number of people with parking toll tags or smart cards. In general, PGI systems use a combination of static systems and DMS to disseminate information to motorists regarding the availability of parking spaces.

Integrated Corridor Management

Integrated corridor management (ICM) can be defined as a collection of operational strategies and advanced technologies that allow transportation subsystems, managed by one or more transportation agencies, to operate in a coordinated and integrated manner, thereby increasing overall system throughput and enhancing the mobility, reliability, and safety of corridor users. An ICM initiative consists of the operational coordination of multiple transportation networks and cross-network connections that make up a corridor, and the coordination of institutions responsible for corridor mobility.[32] The transportation subsystems could include freeways, arterials, parking, public transit, and freight facilities.

ICM includes a set of procedures, processes, and information systems that support transportation system managers in making proactive, coordinated decisions involving multimodal and multifacility transportation systems. With ICM, transportation professionals manage the transportation corridor as a multimodal system—rather than taking the more traditional TMS approach of managing individual modes and facilities. The United States Department of Transportation (USDOT) started the ICM initiative in 2005 with the goal to manage a transportation corridor as a whole system and to optimize the use of the transportation resources across all modes of transportation within the corridor.[33]

Needs of ICM Strategies

The basic principle of ICM is that the management of individual transportation corridor components, such as modes and facilities, can be much more effective if accomplished in a coordinated and integrated manner. One of the documents produced by the USDOT ICM program[34] reviewed the needs identified for eight demonstration sites selected by the ICM program to investigate appropriate ICM strategies. The following is a summary of the high-level needs that were identified:

- Information sharing and coordination across different transportation systems
- Optimization of the supply (available capacity of various modes and facilities) and demand for transportation services within the corridor
- Need for an informative decision-making process to assist in ICM implementation
- Need to disseminate traveler information that affects traveler’s route, mode, and travel time decisions
- Analysis and prediction of system performance for planning and real-time operations
- Estimation of the behavior of travelers in response to advanced management strategies

USDOT ICM Program

The USDOT's seven-year ICM initiative comprises four phases.[35,36] These phases aim at the development of new approaches for efficiently managing existing assets within a corridor. Elements of Phases 2 to 4 are expected to occur concurrently.

Phase 1 was completed in early 2006 and was focused on reviewing existing corridor management practices, initial feasibility research, and the development of initial technical guidance, including "ICM Implementation Guidance"[37] and "ICMS Concept of Operations for a Generic Corridor."[38] An ICM ConOps document identifies the intended ICM strategies for implementation, the potential benefits, and the stakeholders involved. Phase 2 has developed analytic tools and methods that enable the implementation and evaluation of ICM strategies. Phase 3 has included the modeling, demonstration, and evaluation of ICM approaches that appear to offer the greatest potential. In Phase 3, ICM approaches developed by three demonstration sites were modeled using different multi-resolution simulation platforms. Initially, all eight sites developed site-specific ConOps and requirements documents. Three sites among the eight sites were selected for the application of analysis, modeling, and simulation (AMS) methods. These three sites were Dallas, TX; Minneapolis, MN; and San Diego, CA. Phase 4 has involved outreach and knowledge and technology transfer to allow practitioners around the country to implement ICM strategies. The systems in Dallas and San Diego have entered the initial operations phase.

Other regions have started implementing ICM strategies of the types investigated by the ICM initiative. Examples of such implementations include the I-80 corridor in Oakland, CA; the I-5 and US 97/OR 58 California/Oregon Advanced Transportation Systems (COATS); the I-75 corridor in Detroit, MI; the Gary-Chicago-Milwaukee ITS Priority Corridor; the Niagara International Transportation Technology Coalition (NITTEC); the I-10 corridor in Phoenix, AZ; and the Tri-State Integrated Corridor Management System (California, Oregon, and Nevada).

Operational Strategies to Satisfy ICM Needs

A number of ICM strategies have been proposed to satisfy the needs summarized earlier. According to USDOT documents, the ICM strategies can be organized into four categories:[39]

- Information sharing and coordination between agencies
- Improvement of operational efficiency based on coordinated operation
- Promotion of cross-network shifts
- Planning for operations

The following are examples of strategies that can be proposed under each of the four categories.

1. Sharing and coordination. Examples of these strategies include the following:

- Collection of real-time data for freeways, arterials, transit vehicles, and associated parking facilities
- Coordinated support responses to reduce the impact of events, including sharing of information between transportation system operators and public safety during emergencies and incidents
- Construction and maintenance coordination and information sharing across all facilities and modes
- Sharing of information on transit services regarding incidents, service status, vehicle location, and transit schedules
- Standard definition of actions for coordination

2. Improvement of operational efficiency based on coordinated operation. These strategies involve coordinated operation between freeways, managed lanes, arterial roadways, and transit facilities for optimal use of available capacity and accommodation of cross-network route and mode shifts, as in the examples below:

   - Modification of arterial signal timing to accommodate traffic shifting from freeways
   - Modification of ramp metering rates to accommodate traffic shifting from arterial roadways
   - Modification of bus schedules to accommodate mode shift due to incidents
   - Parking management to accommodate shift in demands
   - Signal transit vehicles as priority if the vehicle is behind schedule
   - Multimodal electronic payment of managed lane, transit, and parking
   - Signal preemption and best route recommendation for emergency vehicles

3. Promotion of network shifts. This capability includes the following:

   - Disseminating information to allow selection of alternative routes, schedules, and modes of travel based on current or anticipated travel conditions
   - Promoting route shifts between roadways by disseminating traveler information
   - Promoting modal shifts from roadways to transit by disseminating traveler information
   - Promoting shifts between transit facilities by disseminating traveler information
   - Rerouting buses around major incidents

4. Planning for operations. Examples of these strategies include the following:

   - Data archiving and modeling
   - Planning of coordinated incident management activities

- Modeling and analysis of converting regular lanes to managed lanes
- Analysis of optimized transit capacity in coordination with highway capacity during recurrent congestion, incidents, and special events
- Analysis of lane use control (reversible lanes/contraflow)
- Coordination of scheduled maintenance and construction activities between agencies
- Bus-on-shoulder lane or congestion bypass modeling and analysis

Road Weather Management (RWM)

Weather has a major effect on the safety of the transportation system. Between 2005 and 2008, inclement weather was a factor in 1.3 million crashes that caused 6,000 fatalities and 400,000 injuries.[40] In addition, weather is the second largest cause of nonrecurring congestion after incidents. Road weather management (RWM) has been proposed to mitigate weather impacts. RWM strategies can be developed and applied for all facility types and modes of transportation. Further discussion of these systems can be found in Module 4.

Transportation Management Centers

Transportation management centers (TMCs) are the hub or focal point of transportation management systems. A TMC is where information about the transportation network, including the freeway system, traffic signal system, and transit system, is collected, processed, fused, and used to make decisions to effectively manage the system. The TMC also is the focal point of coordinating with and communicating transportation-related information to the media, information service providers, emergency and enforcement agencies, other transportation agencies, and the motoring public.

Depending on the size of the region and the functions performed, the number and types of activities at the TMC could be very complex. A TMC houses central equipment, software, and personnel to monitor, control, and operate the transportation system. Video and data from field infrastructure devices, mobile units, and other agencies in the region are received at the TMC, allowing the system software and operator to assess the state of the system. Using this assessment, the central software determines the appropriate management strategies and provides recommendations to the TMC operators to execute specific strategies or protocols. The TMC can also disseminate information to travelers through DMS and other management devices and share information with other transportation and emergency agencies, information service providers, and other related agencies.

Transportation management centers can be classified based on their functionality and scope into the three types discussed below.[41, 42] Although traditionally these three types of centers have been implemented in separate physical facilities, multijurisdictional centers have been implemented in recent years that combine the functionality of the three types of centers.

Freeway Management Center (FMC): FMCs typically are responsible for the monitoring and control of traffic on limited-access facilities. One of the main functionalities of these centers is incident management that involves the detection, verification, response, and active management of incidents and the dissemination of related information to travelers (incident management is discussed in Module 4). FMCs are also the command centers for other freeway management and operation strategies discussed in this module and Module 4, including ramp metering, managed lanes, active traffic management strategies, smart work zones, and weather-responsive traffic management. The FMC typically manages a large number of field devices installed on the freeway corridors, including point traffic detectors, vehicle probe readers, CCTV cameras, dynamic messages signs, road weather information system units, traffic controllers, and ramp signals. FMCs also communicate and coordinate with other agencies in the region, such as law enforcement, emergency services, hazardous materials (HAZMAT) teams, towing truck companies, and maintenance contractors. In addition, FMCs receive motorist calls and disseminate transportation system information.

Traffic Signal System Center: These centers focus on monitoring and controlling traffic signals on urban surface street networks. The functions include decision making regarding implementing and expanding signal systems, updating the signal control parameters, and monitoring the equipment’s functional status. The centers monitor the performance of traffic and update the signal timing when needed. The level of monitoring and response and the degree of the automation of these tasks depend on the center’s sophistication. Traffic signal system centers are expected to start implementing advanced incident management and active management strategies that are applicable to urban street management. The signal system center may also interact with the freeway management centers, transit management centers, emergency management, and other centers in the region and participate in the implementation of transportation systems management and operations (TSM&O) and ICM strategies, discussed earlier.

Transit Management Center (TRMC): TRMCs track and manage transit fleets. Depending on the center, the fleet could include buses, rail cars, and paratransit vehicles. A number of technologies have been implemented to track and monitor transit vehicle location and speed and other parameters critical to transit management. Details of transit management and associated technologies are presented in Module 7, “Public Transportation.” As with other centers, the TRMC should coordinate various functions with other centers in the region and participate in ICM and TSM&O initiatives in the region. This may include, for example, coordinating transit signal priority with traffic signal control systems and preferential treatments of transit on managed lanes and metered ramps with the FMC. It is also possible to coordinate with freeway and signal control centers to identify alternative routes and modes in the case of incidents and to inform these centers of any unusual traffic conditions observed by transit drivers.

Coordination with public safety agencies is needed to transmit mayday signals from transit vehicles or transit stations.

In real-world implementations, the FMC functionalities are included in what is referred to as a regional traffic management center or a department of transportation or toll authority traffic management center. The term FMC is not commonly used. Sometimes the centers are responsible for managing ITS deployment on arterial streets in addition to freeways. Similarly, a variety of names are used to reference traffic signal centers and TRMCs in real-world implementation. An actual TMC implementation may serve a single jurisdiction or multiple jurisdictions within a metropolitan area, a large region, or even an entire State. In some regions, regional multijurisdictional TMCs have been established that include various transportation management and enforcement agencies in the region.

Well-managed and well-operated traffic management centers are critical to the success of TMS. Advanced traffic management centers have been established around the United States. However, a 2005 U.S. Government Accountability Office (GAO) study found that some traffic management centers do not have staff dedicated to monitoring traffic conditions, which limits their ability to manage congestion.[43]

A critical consideration is establishing effective coordination among regional TMCs. Coordination should be considered during all stages of TMC implementation, including the initial planning, design, implementation, and operation of the TMC. The most important element of center-to-center coordination is the sharing of information. Information can be shared in real time, during events such as incidents, work zones, and special events; offline as part of event planning; or following the event, such as in a follow-up evaluation.[44] In event planning, agencies should agree on detailed actions to be performed, who is responsible for each action, and how information will be shared during the event. During the event, detailed information regarding the event and associated management activities should be shared. The post-event evaluation should include step-by-step analysis of the management activities and recommendations for improvements. Another important example of center-to-center coordination and sharing of information is the need to coordinate signal control in adjacent jurisdictions. Center-to-center coordination is a key component in TSM&O and ICM implementations because it allows agencies to work together to maximize the utilization of all capabilities to achieve agency and regional goals and objectives.

Florida's Department of Transportation TMC Software Statewide, with videos describing deployment (www.itsa.wikispaces.net/file/view/SUNGUIDE1.mp4, www.itsa.wikispaces.net/file/view/SUNGUIDE2.mp4, and www.itsa.wikispaces.net/file/view/SUNGUIDE3.mp4).

TMS Device Maintenance

A critical component of TMS is device maintenance and replacement. The FHWA's *Guidelines for Transportation Management Systems Maintenance Concept and Plans*[45] defines maintenance as "a series of methodical, ongoing activities designed to minimize the occurrence of systemic failures and to mitigate their impacts when failures do occur. These activities include replacing worn components, installing updated hardware and software, tuning the systems, and anticipating and correcting potential problems and deficiencies." Maintenance planning and continuous funding is an important part of TMS and should be considered in the short- and long-term planning of these systems. Maintenance activities can be categorized as follows:

- Preventive maintenance is scheduled operations performed to keep the systems operating and to extend the active life of devices and subsystems. It can be as simple as cleaning cabinets and cable runs and conduits or securing wiring and PC board connections or it can involve scheduling preemptive repair or replacing components or entire devices. The scheduling of preventive maintenance can be as simple as using past experience to anticipate when various devices should receive attention, or it can involve the use of automated management systems that analyze a number of factors and produce a schedule.
- Responsive, or reactive, maintenance is performing the repair or replacement in response to a failure or damage caused by an event. Responsive maintenance operations are initiated by a fault or trouble report generated by a person or software that is monitoring the system.
- Emergency maintenance is similar to responsive maintenance in that it is initiated by a fault or a report. However, in emergency management the fault is more serious and requires immediate action.

A key part of all maintenance is having a complete, manageable inventory (asset management) of all devices. Automated support software can be an ideal way to maintain the inventory as well as assist in the maintenance operations—both preventive and responsive. Maintenance decision support systems (MDSS) have been developed under a pooled-fund study that can be useful for ITS device maintenance, but their primary use is for roadway maintenance, particularly snow and ice mitigation (see www.meridian-enviro.com/mdss/pfs/). Of particular interest to this discussion are ITS maintenance management systems (MMS) and fiber management systems (FMS). These systems maintain the inventory and status of devices and fiber-optic cable, respectively. An example of a combined MMS/FMS, which was developed at the request of the Florida DOT, is the ITS facility management system (see www.dot.state.fl.us/trafficoperatio ns/ITS/Projects_Telecom/ITSFM/ITSFM.shtm). As ITS operations grow and age, the need for an automated system increases. Most TMS agencies have up-time goals that challenge the maintenance team to keep devices operational at least a certain percentage of the time, for example 90–95 percent. Only automated systems can both organize the maintenance activities and track them.

Maintenance can either be performed in-house by staff or be outsourced to others, usually private contractors. Most TMS devices in the United States are maintained by in-house public works staff or outsourced to another public agency, such as a county contracting with the large city in the county to maintain their signals and, increasingly, ITS devices. State-run freeway management systems have outsourced maintenance to private contractors. More information can be found in the FHWA's *Guidelines for Transportation Management Systems Maintenance Concept and Plans*,[45] which summarizes TMS maintenance practices used by State and local transportation agencies, identifies lessons learned from those practices, and offers professional analysis and recommendations for development of a comprehensive maintenance program for traffic management systems.

Transportation Data

Intelligent transportation systems, including TMS, are generating a wealth of data that can be archived and used in combination with data fusion, traffic analysis, simulation modeling, and data mining to support transportation system performance measurement and decision-making processes. Detailed data is currently being collected for real-time transportation agency system operations and management, including detector data, automatic vehicle identification (AVI) and automatic vehicle location (AVL) data, transit data, freight data, private sector travel time data, incident data, special event data, construction data, and weather data. However, until recently this data has not been archived and used to support transportation system management. In addition, some agencies are concerned about tort liability, particularly when archiving individual vehicle data or video.

ITS data archiving, also referred to as ITS data warehousing, is defined as "the systematic retention and re-use of transportation data that is typically collected to fulfill real-time transportation operation and management needs."[46] The NITSA includes the archived data user service (ADUS)[47,48] that is mapped to three service packages: ITS Data Mart, ITS Data Warehouse, and ITS Virtual Data Warehouse. In ITS architecture terminology, the ITS Data Mart service package provides an archive that houses data collected and owned by a single agency. The ITS Data Warehouse service package allows the collection of data from multiple agencies, with data sources spanning modal and jurisdictional boundaries. The ITS Virtual Data Warehouse service package can provide the same access to multimodal, multidimensional data from varied data sources as in the ITS Data Warehouse service package. However, this access is provided using connections between physically distributed ITS archives that are each locally managed. Requests for data are made through a user application, and the data is provided by the local archives and dynamically translated to the user application. It should be noted that the term "data warehouse" has been used in real-world applications even for single agency data archives, which is referred to in the NITSA as a Data Mart.

Traditionally, many ITS operations agencies have focused on real-time management of transportation systems and considered data archiving the responsibility of planning agencies. Increasingly, however, operation agencies are realizing the value of real-time data. Data archiving provides a number of benefits to transportation agencies.[46] First, the data assists in assessing and predicting system performance measures and the impacts of implementing advanced strategies on system performance. Second, the data can be used as inputs to decision support tools to allow proactive management of the transportation system. Operations data can be used to predict the locations and magnitude of potential problems and to support the selection of strategies for preventing or mitigating the problem. Furthermore, data archiving permits transportation agencies to maximize their investments in data collection infrastructure by using the data for other applications that require data collection, such as planning, modeling, design, operations, and research. Collecting data for these applications using manual methods or special studies is expensive and in many cases provides less detailed data in time and space than can be collected through TMC operations.

There are a number of issues to be addressed when considering archiving operational data and the use of data.[46] Data archiving needs to be driven by agency operational objectives. Without effective archiving and use of data, it is not possible to perform performance measurement and management. This is important for all facility types and modes (freeways, arterials, transit, and freight). In many cases, combining data from more sources and for different facilities and modes allows better and more informative analysis.

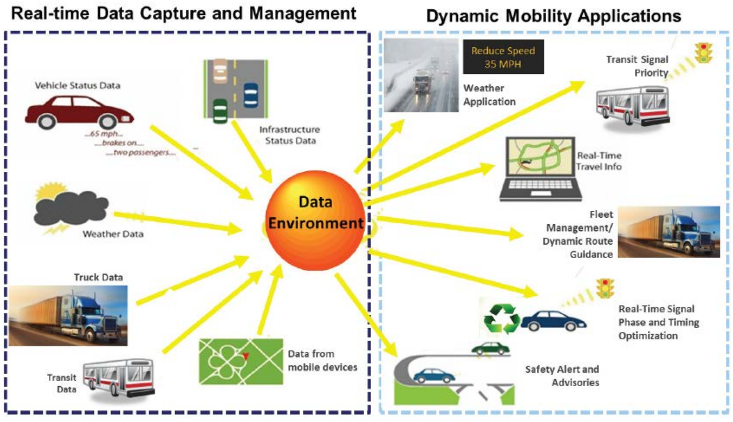
In some cases, operations data has been archived but has not been widely distributed or analyzed because of the required additional resources, effort, and funds. There is a need to identify the agency that takes the leading role in archiving the data and funding sources. A decision also needs to be made as to whether the data archive will be implemented as a central data warehouse or as a virtual data warehouse, with several agencies operating their own individual data archives that will be connected and integrated through computer interfaces. It has been suggested that a good approach to archiving data is to start with the implementation of a small prototype, archiving limited data types and then expanding to archiving more data sources and more complex systems with time.[46] In all cases, adequate documentation of the data archive and the associated data collection system is necessary.

Another decision that needs to be made is the aggregation level of the data collected from traffic detectors and AVI readers. Aggregation refers to the time interval at which data is summarized. Some data archiving systems archive the collected data at the level of detail used for the data collection (e.g., at a 20-second interval for detector data), whereas others aggregate these measurements to 5- to 15-minute values to save computer storage space and to reduce data processing time.

An essential component of data archiving is quality control. Quality control techniques for archived data should address suspect or erroneous data (illogical or improbable data values), missing data, and systematically inaccurate data (inaccurate because of equipment measurement error but within the range of logical values). One of two different approaches can be selected to deal with data that has failed quality control. The first is to simply flag the data records that have failed quality control. The second is to replace the data records that are not of acceptable quality with better estimates. This latter approach is referred to as data imputation.

USDOT has recently established the Real-Time Data Capture and Management Research Program to support the active acquisition and systematic provision of integrated, multisource data that enhances current operational practices and transform future surface transportation systems management. The objective of the program is to enable the development of environments that support the collection, management, integration, and application of real-time transportation data or data sets (see Figure 9).

Figure 9. Data Capture Environment Envisioned in the USDOT Program[49]



Assessment of Implementation Alternatives

The first step in assessing improvement alternatives is to define the problems and issues associated with the transportation system based on stakeholder inputs, all information available about the system, and analysis results. Once this is done, a set of TMS deployment alternatives can be identified to potentially address the identified problems and issues. The decision to select between the TMS deployment alternatives requires the evaluation and ranking of these alternatives relative to each other and possibly to other improvement alternatives. In general, two main approaches have been used in previous studies for the evaluation and ranking of ITS project alternatives:[50]

- The first approach is the utility-based approach, also referred to as the goal-oriented or the performance-based approach. The utility-based approach is based on the calculation of a utility value for each ITS deployment alternative to indicate its ability to meet identified ITS goals and/or performance measures (project ranking criteria).

- The second approach is the economic approach, also referred to as the benefit-cost approach. The economic analysis approach compares ITS deployment alternatives based on their benefit-to-cost ratios or their net present worth (or annualized) benefits. The benefits in mobility, reliability, safety, environmental impacts, and other benefits will have to be converted to dollar values in this approach.

The Research and Innovative Technology Administration (RITA) is maintaining an ITS Benefits Database (www.itsbenefits.its.dot.gov/) that documents the impacts of ITS deployments as reported in national and international ITS evaluation studies. The benefit information can be searched by application area, performance goal, and evaluation location (State or country). RITA also collects and maintains information on ITS costs in the ITS Unit Costs Database (www.itscosts.its.dot.gov/). The costs in the database include the capital costs in addition to the operations and maintenance costs. These costs are presented in a range to capture the lows and highs of the cost elements from the different data sources that were used in deriving the database. The cost data is useful in developing project cost estimates during the planning and evaluation processes.

The FHWA Office of Operations developed the *Benefit/Cost Analysis for Operations Planning Desk Reference* to provide practical guidance, tools, and information for conducting benefit-cost analysis for TSM&O strategies. Two products were developed as part of this project. The Operations Benefit/Cost Analysis Desk Reference provides guidance on how to estimate the benefits and costs of operations.[51] A supporting spreadsheet-based decision support tool (the Tool for Operations Benefit/Cost, TOPS-BC) was also developed to provide a framework and relevant information to conduct benefit-cost analysis.

As will be explained in the next section, a number of other tools have been developed to support the evaluation of ITS alternatives. These tools can be used as part of the ITS evaluation using the utility-based approach and/or the economic approach. However, these tools may not be sufficient to evaluate all the performance measures that need to be considered in the evaluation and ranking of ITS deployment alternatives. For this reason, the evaluations of some of the quantitative and qualitative measures may need to be done using other processes, in combination with the use of the supporting tools.

A number of tools have been developed to assess the performance of transportation systems and to estimate impacts of alternative strategies to manage the performance. In general, these tools can be classified as sketch planning tools, offline operational-level assessment tools, and real-time assessment tools.

The evaluation of ITS as part of the transportation system planning process has been mainly performed using sketch planning tools such as the ITS Deployment Analysis

System (IDAS), developed for the Federal Highway Administration,[52] and a tool referred to as the Florida ITS evaluation tool (FITSEVAL), to evaluate ITS deployments in Florida at the planning level.[26] The assessment of ITS at the planning and operation levels requires more detailed analysis. This analysis can be based on data from different sources and/or more detailed modeling techniques such as mesoscopic simulation and microscopic simulation models. Tools have been developed for offline and real-time assessment of system performance and alternative strategies.

The FHWA Traffic Analysis Tools Program has developed 13 documents to date to support transportation agencies in modeling their systems.[53] An ongoing effort is developing a method and tool to assess ATM strategies for inclusion in a future version of the *Highway Capacity Manual.*[54]

Role of Connected Vehicle Infrastructure in TMS

Connected vehicles offer the potential for significantly enhancing all processes of transportation system management. First, in the determination process, detailed probe data collected from connected vehicles' onboard units will allow much more detailed and accurate estimations of the system State to feed the management strategy. In addition, the ability to communicate information between transportation management centers, drivers, and vehicles through connected vehicle technologies will allow new methods of executing management strategies. Furthermore, information collected from the connected vehicle regarding performance and responses to management strategies will allow superior evaluation of these strategies, both in real-time operations and in off-line planning for operations. This ability will allow a more informed decision regarding the revision and fine-tuning of these strategies. More detailed discussion of the connected vehicle system and its applications to safety, mobility, and environmental impact reductions can be found in Module 13, "Connected Vehicles." This section presents an overview of the use of connected vehicle technologies to support traffic management. Another related area is intersection safety, which is covered by the USDOT Connected Vehicle Safety Program**.**

Two key components of the mobility element of the USDOT program are the Real-Time Data Capture and Management program and the Dynamic Mobility Applications program.[55] The data capture and management program focuses on the access and use of high-quality, real-time, multimodal data from connected vehicles that can be used to enhance transportation operations and management practices. The dynamic mobility applications program aims at providing transportation agencies with real-time monitoring and management tools in the connected vehicle environment. Both of these programs address applications that are of strong interest to transportation management. The USDOT Connected Vehicle Environmental Application program also addresses applications related to traffic management that will reduce the environmental impacts of the transportation system and the weather impacts on the transportation system.

The onboard units will facilitate gathering more detailed information. In addition to vehicle location, speed, and heading, much more data will be gathered from the vehicle. The roadside and network services will be able to analyze the unit's situation analysis and generate management and travel controls and messages. The in-vehicle systems will be able to present messages to vehicle operators. A range of traffic control and management applications of connected vehicle systems has been proposed, including the following:[56]

- Applications that integrate adaptive strategies across modes and facilities
- Weather-responsive management
- Use of adaptive signal controls that involves monitoring approaching traffic streams to create phase and timing plans that optimize flow
- Broadcasting of real-time data about traffic signal phase and timing (referred to as SPaT data) to vehicles
- Traffic signal prioritization for transit vehicles and preemption for emergency vehicles
- Active traffic management applications such as speed management
- Automated highway applications such as cooperative adaptive cruise control for managing headway and capacity
- Corridor and regional management

Case Studies

This module shows the wide variety of ITS implementations that can be categorized as TMS. In addition, a large number of successful case studies of TMS are available. Below are two examples.

South Florida Express Lanes and Ramp Metering

The Miami–Ft. Lauderdale region is creating a 21-mile managed lane facility on I-95, between I-395 and I-595, with a longer-term goal of providing a network of managed lanes throughout the region. Acceptable conditions on the managed lane network is ensured through the use of variable pricing based on demand, and the network itself is used as the backbone of a bus rapid transit system that is subsidized through the toll revenues. Approximately half of the ultimate 21 miles of the managed lanes became operational in 2010. Adaptive ramp metering has been implemented on this section. Other traffic management strategies include state-of-the-art TMC and incident management operations.

This project increased the occupancy requirement on HOV lanes from HOV 2+ to HOV 3+ and requires all carpools to register. The new occupancy requirement will ensure that the lanes remain operational at acceptable levels and will create some excess capacity for priced vehicles. Dynamic message signs show the current charge for vehicles not meeting the occupancy requirement to use the managed lanes. In addition, transit service enhancements were included in the project.

The deployment has considerably improved the overall operational performance of I-95. Customers, including transit riders, who elect to use the express lanes have significantly increased their travel speed during the morning peak (southbound) and evening peak (northbound) periods, from an average speed in the HOV lane of approximately 20 mph to a monthly average of 64 mph and 56 mph, respectively. Drivers travelling via the general purpose lanes have also experienced a significant peak period increase in average travel speed since implementation of the managed lane, from an average of approximately 15 mph (southbound) and 20 mph (northbound) to a monthly average of 51 mph and 41 mph, respectively. Average volumes along the express lanes in the morning and evening peak periods were over 7,400 vehicles (approximately 28 percent of the total I-95 traffic). These vehicles traveled at speeds greater than 45 mph during peak periods, which exceeded the Federal requirement for a minimal speed of 45 mph on HOV to HOT lane conversion facilities.

Some of the lessons learned from the project follow:

- Define a strong project vision.
- Establish a comprehensive schedule.
- Develop a concept of operations.
- Involve design and operations professionals in planning.
- Provide the project manager with direct authority.
- Consider using current contract consultants.
- Anticipate transit technical challenges.
- Use ongoing outreach and media to maintain communication with travelers.
- Keep public officials and the public informed of changes in project operations and challenges.
- Be prepared for a shift in marketing approach.

Seattle (Lake Washington) SR 520 Project

The Washington State Department of Transportation has introduced new tolls on SR 520, setting toll rates on the facility based on demand to avoid the buildup of congestion and the loss of roadway capacity when it is most needed. The project deployed open-road electronic toll collection equipment, allowing tolls to be collected at freeway speeds. Substantial transit improvements have also been implemented to further reduce congestion in the SR 520 corridor and to provide travelers real alternatives to driving and paying the congestion tolls.

Dynamic message signs displaying travel time information were installed on SR 520, SR 522, and I-405. Drivers will have real-time travel times on alternate routes to make decisions about the best route to travel. In addition, new DMS will be installed above each lane about every half mile on the SR 520 and I-90 corridors. This system will automatically use information gathered from the roadway to vary the speed limits on the corridors, alert drivers to congestion or incidents, and notify drivers of blocked lanes ahead. Additional traffic demand management and telecommuting elements have also been implemented.

Some lessons learned from the project include the following:

- A portion of the toll system procurement has been successfully managed by the site partners so as to avoid significant impacts to schedule.
- Recent experience in deploying active traffic management in the I-5 corridor contributed to the success of SR 520 ATM deployment.
- There a significant political dimension of toll rate setting.

Summary

As described in this module, a variety of TMS strategies are contributing significantly to reducing the congestion problems and the unreliability of the transportation systems around the country. TMS play a major role in enhancing safety, transportation security, and emergency response. This contribution will only increase in the coming years as the complexity and effectiveness of the available technologies and associated strategies continue to increase at a very high rate. The regional collaboration and integrated multimodal, multifacility TMS will be a major component in the coming years, as envisioned in the TMS&O and ICM initiatives. ATDM and ICM strategies are just starting to be implemented and evaluated, and more agencies will be implementing these strategies as they better understand their effectiveness.

Data archiving, analysis, use, and reporting will provide major benefits to agencies in providing opportunities to measure performance and support decision making. New data sources and products to collect the data will be available in the coming years, and the understanding of the types and quality of the data will be important elements of TMS. Measuring performance and benefit-cost analyses become even more critical to these agencies with the MAP-21 focus on performance measurement and management. The application of AMS methods to support agency operations, both offline and real time, will also have a role in future TMS applications.

As described in this module, statistical, artificial intelligence, and simulation techniques have been proposed to allow short-term prediction of transportation system conditions. The utilization of predictive methods to predict traffic conditions will also be a new component of TMS operations. Congestion pricing and managed lanes will play an important role in TMS as the need for demand management and other sources of funding for the transportation system increase.

As discussed in this module, cooperative vehicle-highway technologies offer the potential for significantly enhancing all processes of transportation system management and have the potential to fundamentally change how transportation systems are managed and operated.

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Table of Abbreviations

ADUS	archived data user service
AMS	analysis, modeling, and simulation
ASCT	adaptive signal control technologies
ATM	active traffic management
ATIS	Advanced Traveler Information Systems
AVI	Automatic vehicle identification
AVL	Automatic vehicle Location
CCTV	Closed-Circuit Television Cameras
ConOp	Concept of Operations
DLS	Dynamic Lane Assignment
DMS	Dynamic Message Signs
DSS	Decision Support System
ESS	Environmental Sensing Stations
ETC	Electronic Toll Collection
ETL	Express Toll Lanes
EVP	Emergency Vehicle Preemption
FHWA	Federal Highway Administration
FMC	Freeway Management Centers
HAR	Highway Advisory Radios
HCM	Highway Capacity Manual
HOT	High Occupancy Toll Lanes
HOV	High Occupancy Vehicles
ICM	Integrated Corridor Management
ITS	Intelligent Transportation Systems
MPOs	Metropolitan Planning Organizations
MUTCD	Manual on Uniform Traffic Control Devices
NITSA	National ITS Architecture
NTCIP	National Transportation Communications for ITS Protocol
PDSL	Priced Dynamic Shoulder Lanes
PGI	Parking Guidance Information Systems
RITA	Research and Innovative Technology Administration
RTMC	Regional Traffic Management Center
RWM	Road Weather Management
SHRP2	Second Strategic Highway Research Program
SOV	Single-Occupant Vehicles
SPaT	Signal Phase and Timing
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TMC	Transportation Management Centers
TMS	Transportation Management Systems
TOPS-BC	Tool for Operations Benefit/Cost
TOT	Truck-Only Toll lane
TRMC	Transit Management Centers

TRS	Traffic Responsive Systems
TSM&O	Transportation system management and operations
TSP	Transit Signal Priority
USDOT	United States Department of Transportation
VMS	Variable Message Signs