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16. Abstract

Over the past several decades, the Texas Department of Transportation (TxDOT) has made a significant investment in deploying and developing intelligent transportation systems (ITS) devices, such as closed-circuit television (CCTV), traffic sensors, and dynamic message signs (DMS), to assist in managing traffic operations. However, as these systems have matured and as financial resources have become more constrained, TxDOT needs to become more strategic in their decision-making as to when and where to deploy new ITS devices and systems and when and where to continue supporting and/or upgrading systems that have met their life expectancy. The goal of this project was to develop guidelines, criteria, and procedures to assist TxDOT in their decision-making specific to installing, repairing, and/or removing ITS field devices and systems. Specifically, through this project the research team assisted TxDOT by: 1) developing warrant conditions and criteria for assessing when and where to install new ITS devices and systems, 2) providing sunset requirements and criteria for determining when to no longer support deployed ITS devices and systems, and 3) developing an analytical framework for identifying and prioritizing mission-critical devices and systems for upgrade and maintenance.

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WARRANTS AND CRITERIA FOR INSTALLING AND SUNSETTING TXDOT ITS EQUIPMENT

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer (researcher) in charge of the project was Kevin N. Balke, P.E. #66529.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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CHAPTER 1. INTRODUCTION

Over the past several decades, the Texas Department of Transportation (TxDOT) has made a significant investment in deploying and developing intelligent transportation systems (ITS) devices, such as closed-circuit television (CCTV), traffic sensors, and dynamic message signs (DMSs), to assist in managing traffic operations. However, as these systems have matured and as financial resources have become more constrained, TxDOT needs to become more strategic in their decision-making as to when and where to deploy new ITS devices and systems and when and where to continue supporting and/or upgrading systems that have met their life expectancies. The goal of this project was to develop guidelines, criteria, and procedures to assist TxDOT in their decision-making specific to installing, repairing, and/or removing ITS field devices and systems. Specifically through this project, the research team assisted TxDOT by:

- Developing warrant conditions and criteria for assessing when and where to install new ITS devices and systems.
- Providing sunset requirements and criteria for determining when to no longer support deployed ITS devices and systems.
- Developing an analytical framework for identifying and prioritizing mission-critical devices and systems for upgrade and maintenance.

BACKGROUND AND SIGNIFICANCE

Intelligent transportation systems devices are one tool in TxDOT's toolbox for improving safety and operations on the state's highways. TxDOT routinely installs ITS devices, such as closed-circuit television, vehicle detection systems, and dynamic message signs to help them better manage operations, improve safety, and reduce the effects of incidents on Texas highways. Although these can be valuable assets in managing traffic and improving safety, they need to be managed as an asset just like any other part of the transportation infrastructure. As with many types of advanced technology (i.e., cellular phone technology or communications technology), these technologies tend to have a short product life—a new, better, faster device always seems to be right around the corner. It seems that as soon as TxDOT purchases a device or makes a commitment to a particular type of technology or installs a technology to perform a mission-critical function, it soon becomes obsolete. Once new ITS devices or systems are installed, TxDOT is making a long-term commitment, in terms of resources, to operate and maintain these technologies, and as resources become tighter for TxDOT, operating and maintaining these devices and systems at a high level of functionality also becomes more difficult. In reality, ITS devices and systems and their associated communications infrastructure) can be viewed as infrastructure asset.

Through this research project, the research team examined strategies, criteria, and tools that TxDOT could potentially use to help manage their ITS deployments as an asset. Managing ITS devices as assets will allow TxDOT and other regional stakeholders to become more strategic and fiscally responsible in the use of their limited ITS deployment and maintenance funds. The policies, practices, and procedures developed during this research effort will allow regions to prioritize their deployments as well as ensure that deployed systems are maintained to their highest potentials. The findings from this research can help TxDOT deploy and maintain mission-critical ITS devices.

PROJECT GOALS AND OBJECTIVES

The goal of this research project was to assist TxDOT in identifying criteria and requirements for installing, replacing, and/or removing ITS field devices on Texas highways. The specific goals of this research effort were as follows:

1. Summarize the existing best practices and strategies for deploying, operating, and maintaining ITS field devices.
2. Identify key factors, criteria, and conditions justifying the installation of specific ITS field devices, such as traffic sensors, closed-circuit television, and permanent dynamic message signs.
3. Identify key factors affecting the maintenance of these devices and removal of these devices.
4. Develop criteria and documentation procedures to justify the installation, replacement, and removal of these devices to and from the field.
5. Develop a set of tools that can assist TxDOT in assessing and justifying the need to install and/or repair or remove ITS field devices on Texas highways.

SCOPE

The scope of this project was limited to the development of guidelines and criteria for installing, replacing, and/or retiring ITS field devices, specifically traffic sensors, CCTV cameras, and permanent DMSs. The scope of this project did not include the development of guidelines and criteria for installing, replacing, and/or removing central system software or physical communications media (such as fiber optics, copper wire, etc.). Ancillary devices used to connect field hardware systems to the communications network (such as codecs, switches, routers, etc.) were not included in the scope of this project.

STRUCTURE OF REPORT

This report is divided into eight additional sections, each corresponding to major tasks associated with this project. Chapter 2 of this report provides a summary of the current practices and policies used in other states for deploying, operating, and maintaining ITS field devices. Following that chapter, the research team examines the current policies and practices used in several TxDOT districts related to installing, repairing, and replacing ITS devices. In the Chapter 4, the research team discusses factors affecting the installation and maintenance decisions related to ITS devices. Chapter 5 of the report provides proposed warrant criteria and sunset requirements for TxDOT ITS devices. Chapter 6 of this report provides an assessment of currently available asset management/risk management tools available to TxDOT for supporting ITS equipment deployments. In Chapter 7, the research team discusses how to use a risk-based approach for managing and prioritizing ITS assets. The final chapter of the report provides a summary and recommendations developed as part of this research effort.

CHAPTER 2. ASSESSMENT OF CURRENT PRACTICES IN OTHER STATES

The Texas A&M Transportation Institute (TTI) research team conducted a review and assessment of current practices used by other state departments of transportation (DOTs) for determining when and where to install new ITS devices and systems or replace and/or retire existing ITS devices and systems. The research team reviewed information from other states related to the following:

- Guidelines, criteria, and procedures used to justify the installation, replacement, and/or removal of ITS devices.
- Processes and procedures used to assess and monitor the health of their ITS devices.
- Processes and procedures for collecting the data used in making equipment procurement, deployment, and replacement decisions.
- Decisions support tools and record-keeping systems used to assist decision makers.

At a minimum, the research team reviewed material from the following state DOTs related to their current policies, practices, and procedures for installing, replacing, and retiring ITS field devices:

- Arizona.
- Colorado.
- Florida.
- Georgia.
- Minnesota.
- Oregon.
- Pennsylvania.
- Virginia.
- Washington State.

This chapter contains a summary of the review of guidelines, warrants, and criteria used in these other states to assess the need for, to install, to remove, and to repair ITS devices, specifically closed-circuit television camera, dynamic message signs, and detection systems.

ARIZONA DEPARTMENT OF TRANPSORTATION

The Arizona Department of Transportation (ADOT) provides detailed guidelines and criteria on the placement and design of their ITS devices through their *Freeway Management System Design Guidelines* (*1*) document. The guidelines provide general design and placement criteria for the detection systems, permanent dynamic message signs, and closed-circuit video surveillance systems. The following provides a brief summary of these guidelines.

Mainline Detector Systems

ADOT requires mainline detector stations for the all new sections of urban freeway system. Detector stations should be placed every mile in each direction adjacent to the entrance ramp input detectors (refer to the Ramp Meter Design, Operations, and Maintenance Guidelines).

Non-intrusive detection system technology is often used on retrofit projects. Planning and providing for future non-intrusive detection system technology supporting infrastructure is recommended for new installations. Where feasible, non-intrusive detection system technology is preferably located beyond the outside shoulder of the freeway instead of in the median barrier. New freeway installations should provide supporting infrastructure at a nominal cost for future non-intrusive detection system technology on both sides of the freeway.

Freeway Dynamic Message Signs

Guidelines to consider when master planning the locations of freeway DMSs include the following:

- Two freeway DMSs are desired prior to each system interchange.
- Three-mile spacing along typical urbanized mainline.
- Sufficient distance prior to a closure point such as a tunnel.
- Positioned within view of an existing CCTV camera for message verification.

Freeway DMSs provide key route guidance and diversion information to the freeway driver; therefore, the proper placement of the signs is essential. Individual DMS locations may be tied to specific diversion routes and their associated exit ramp.

Once ADOT has identified a diversion exit ramp for a DMS placement, planners should follow the ADOT guidelines to locate the sign and associated infrastructure. Ideally, this procedure is deployed during the initial roadway design so that the location of the DMS can be worked into the overall signing plan for the roadway segment. However, retrofit projects are common and often require consideration of existing sign placement. DMS placements are considered the highest priority and may necessitate moving other signs.

Closed-Circuit Television

CCTV cameras are located at intervals of approximately one mile on the freeway. It is not unusual to have more than one camera per mile. The proper position of cameras and provision for the required conduit and foundations will be accomplished at the time the freeway management system is designed. One hundred percent coverage of the mainline and tier one crossroads is desired.

Camera locations will be at one of two locations within a typical mile. The first and preferred location is in the close vicinity of the interchange. This position provides visibility of the arterial roadway (especially regionally significant roadways), key ramps, and the mainline freeway. The second potential location is at the midpoint location between interchanges. This midpoint location is desirable to observe the mainline where the interchange CCTV view is blocked by the arterial overcrossing or in cases where roadway geometrics dictate additional cameras.

Other CCTV camera placement criteria include:

- Near the point of intersection (PI) of horizontal curves that restrict visibility to less than one mile.
- At locations with recurring congestion and other high-interest areas.
- On the crests of vertical curves.
- In positions to view adjacent freeway DMS for message verification.
- At complex sites where more than one CCTV may be necessary.

DMS Justification and Warrants

Sections 5.1 through 5.5 of ADOT's *Statewide DMS Masterplan* provide an expanded discussion of the most common justifications of permanent DMSs (*2*). Most justifications include unique warrants that provide a preliminary analysis of whether a permanent DMS is warranted at a candidate location based on needs and conditions. Typical justifications for urban and rural DMS installations in Arizona are identified in Table 1. Districts may determine other justifications on a case-by-case basis.

Table 1. Typical Uses of a DMS by ADOT in Urban and Rural Applications.

Typical Justification for a DMS	Urban	Rural
Traffic Conditions	✓	✓
Route Diversion	✓	✓
Special Events/Site	✓	✓
Evacuation & Reception Routes	✓	✓
Weather Conditions	✓	✓
Flood Hazards	-	✓
Animal Hazards	-	✓

If a device is determined to be warranted, ADOT district engineers are then encouraged to perform a local engineering and planning analysis to determine whether the deployment is feasible at the candidate location. As part of the analysis, ADOT district engineers should examine alternatives such as lower cost or less technology-oriented solutions that fulfill the same needs.

Traffic Management

The purpose of a DMS for traffic management is to provide current traffic status information (crashes, road construction, travel time) so drivers can slow their vehicles, choose which lane or exit to take, and remain informed. Permanent DMSs tend to demand driver attention due to size and readability.

The availability of alternate routes downstream from DMS is important. The intersection of two state roadways offers the opportunity for drivers to divert away from incidents or hazards.

Permanent DMSs are warranted for traffic management if:

1. Events occurring in the area unexpectedly impact or impede traffic (e.g., close a lane, encounter slow traffic in one or more lanes, or events on the shoulder) an average of at least four times per month, ***and***
2. The target area is monitored by CCTV cameras, traffic detectors, or another method of monitoring the conditions, or has travel times for the downstream stretch of road, ***and***

3a. There are acceptable alternate routes with adequate capacity to accept vehicles that may deviate based upon the information, ***or***

3b. The location is a stretch of road where no alternate route is possible and drivers would benefit from information describing the cause and/or extent of delays in order to relieve driver frustration, ***or***

3c. There are horizontal or vertical curves that create safety issues when traffic is stopped unexpectedly, ***and***

4. The route being considered for the DMS has on average:
   - At least 2 hours of peak period travel where traffic flow exceeds 1100 vehicles/hour/lane, ***or***
   - Experiences conditions considered Level of Service (LOS) C, ***or***
   - Experiences a minimum average annual daily traffic (AADT) of:
     - 16,800 for a 2-lane road.
     - 33,600 for a 4-lane road.
     - 50,400 for a 6-lane road.
     - 67,200 for an 8-lane road.

Partial Warrant Criteria: If #1 above is met, the warrant is considered 'Partially Met.' If one or more additional purposes are partially met at this location for this device, the device may be considered 'Warranted.'

Special Events/Sites

The purpose of DMSs for special events is to provide traveler information regarding parking or alternate routes for special events or major venues in order to protect back of queues from rear-end collisions and reduce delay due to unnecessary 'circling the block,' queues, unfamiliarity with the area, or non-participating drivers being caught in event traffic.

Permanent DMSs are warranted for special event venues if:

1. The location contains a venue that hosts ticketed events (typically with rapid and tight arrival and/or departure patterns for a specified start time, such as a sports event), ***and***

2a. The event venue typically houses at least two weekday ticketed events per week (including seasonal sporting events that only occur during the season), ***or***

2b. The event venue, or special site, typically hosts at least one event per year attracting 30,000 visitors or more in one day, ***or***

2c. The event venue or special site typically attracts 1,000,000 visitors, or more, per year, ***and***
3. There is alternate parking or traffic options that could be displayed on a DMS to direct visitors to more preferred options.

Given the increased traffic volumes and congestion levels in urban areas, even minor events could impact travel. As an alternative to a permanent DMS, transit serving special event venues may lessen these volumes and congestion levels.

Placement of a DMS should consider the intent of each sign. For example, further upstream signs are more effective at helping non-event attendees avoid traffic congestion, while signs closer to the venue are effective for directing visitors to open parking and roadway capacity.

Particularly in urban areas, permanent DMSs may exist on state roadways that could serve a special event site. Existence of a DMS location does not guarantee its use for all special events. Use of existing DMSs in support of special event traffic management is applied on a case-by-case basis and is related many times to the ADOT district's encroachment permit process which may, in turn, require supplemental traffic management devices, such as portable DMS units, depending on magnitude of event and resulting anticipated traffic impacts, and as determined by the district permit supervisor, in coordination with the ADOT Transportation Technology Group ITS Support Section Staff.

Evacuation and Reception Routes

The purpose of DMSs for evacuation routes is to provide evacuation or reception route information to drivers during disaster or Homeland Security events.

DMSs, used in conjunction with 5-1-1 systems, offer the potential to become a valuable medium to provide travel information in support of Homeland Security emergency management. During an emergency, normal travel options may be unavailable, meaning drivers may need very basic and specific information on alternative travel options.

Arizona is a low-risk state for emergency management. Neighboring states have higher risk of evacuation; therefore, Arizona has a greater need for reception routes. The impact on planning statewide DMSs is to consider permanent reception or inbound DMSs within 10 miles of entering the state on interstate highways (I-10, I-40, I-15, and I-19) and US routes (linking significant population zones to Arizona, such as US 93 from Las Vegas) as warranted.

Weather Conditions

The purpose of DMSs for weather conditions is to provide road weather information to drivers so drivers can choose either to continue travel on their current route or to adjust their speed, or divert from the trip in anticipation of an upcoming weather hazard. Roadways in Arizona are susceptible to a variety of weather events or consequences of weather, such as flooding, blowing dust, monsoon storms with high winds/lightning, forest fires/smoke, and sudden snow blizzards and snow drifting.

Permanent DMSs are warranted for weather conditions if:

1. The location is prone to weather situations that drivers would not otherwise be forewarned about, ***and***
2. Weather events contribute to a significant number of crashes or road closures such that there are major impacts to drivers (this may include one or more annual closures or crashes on a freeway/interstate highway or 10 or more annual crashes or closures on rural roadways), ***and***
3. There is road weather information available for the area downstream of the candidate DMS location, ***and***
4. There is the capability, either manually by staff members or automated through a condition reporting system, such as a linkage to road weather information system (RWIS), to create event-specific descriptions of weather conditions to be displayed on the DMS, ***and***

5a. There is a recurring need to disseminate event-specific descriptions (rather than a lower technology approach such as activating a flashing warning sign that says "Weather Alert When Flashing"), ***or***

5b. There are options for either alternate routes or services that might be described on the DMS, where drivers may safely wait out extreme conditions, ***or***

5c. Lower technology mitigations (such as flashing beacon signs) have been tried and not proven to generate responses from drivers.

Partial Warrant Criteria: If either #1 or #2 above is met, the warrant is considered 'Partially Met.' If one or more additional purposes are partially met at this location for this device, the device may be considered 'Warranted.'

If the only warrant being met for a DMS is the weather information warrant, then it is recommended that less expensive technologies be considered before deploying permanent a DMS.

Animal Hazards

Arizona has a large elk population in the higher elevations spanning from Williams southeastward to the New Mexico border at Alpine. As in all states, vehicle-game collisions take their toll annually. Vehicle collisions involving >600-lb elk can cause substantial vehicle damage and serious human injury or death. State Route 260, east of Payson, has the nation's most advanced game crossing system with wildlife detection, solar-powered flashers, and roadside DMS units (specific to this game crossing traffic safety system).

In addition to elk, deer, open range cattle, bears, mountain lions, big horn sheep, and other mammals on roadways present hazards to drivers. Animals tend to have certain areas they repeatedly use or man-induced crossings (where elk fencing ends) where there may be a need for permanent DMSs.

If the only need being met for a DMS is an animal hazard, then ADOT recommends that districts consider less expensive technologies before deploying permanent a DMS.

COLORADO DEPARTMENT OF TRANSPORTATION

The Colorado Department of Transportation (CDOT) *Design Guidelines for Including Intelligent Transportation Systems on Projects* provides the following guidance related to use and placement of dynamic message signs (called variable message signs in CDOT's guidelines), CCTV systems, and detection systems (*3*).

Variable Message Signs (VMS)

Variable message signs are electronic signs that may be remotely controlled from a traffic operations/management center. They are used to provide information to the traveling public about roadway conditions that may change due to incidents, sporting events, or weather. They may also be used to provide public information announcements such as America's Missing: Broadcast Emergency Response (AMBER) Alerts for child abduction.

Typical applications and placement include:

- For traveler information and incident management purposes, designers should place VMS prior to major interchanges. Designers can install VMS at other locations if warranted by the need for information dissemination. Designers may also use VMS as a component of traffic management or other intelligent transportation systems solutions.
- Designers may install VMS permanently as either an overhead or ground mounted configuration. Project special provisions are available for both configurations. Designers should use portable VMS only for temporary applications such as work zones or temporary traffic control.

Closed-Circuit Television Camera

CDOT uses closed-circuit television cameras to provide visual information to the traffic operations/management centers. CCTV cameras are an integral part of the incident and traffic management system. Local or regional traffic operations/management centers operate the closed-circuit television cameras using pan, tilt, and zoom capabilities. CCTV cameras give viewers real-time color pictures of critical portions of the interstate and national highway system.

Typical applications and placement include:

- CCTV cameras help the traffic management centers identify and verify incidents and observe traffic volumes.
- CCTV cameras should be used to view high incident areas and recurring hazardous weather areas.
- The visual images from CCTV are used to provide traffic information to the public via the news media.
- Alternate uses for closed-circuit cameras include observing traffic movements within signalized intersections to observe the effectiveness of signal timing designs.
- They should be mounted:
  - On high viewing points such as traffic signal poles.
  - At major structures, such as tunnels and bridges, major intersections.

- o To verify operational status of variable message signs, highway closure gates.
- o Every 5 miles along a major interstate corridor.

Vehicle Detectors

A major component to most ITS solutions in Colorado is vehicle detectors. Traffic management systems depend on vehicle detection to operate traffic signal systems and perform various functions for the major interstate corridors.

Typical applications and placement include:

- Vehicle detectors may be used to provide information about traffic flows including vehicle presence, speed, count, occupancy, type, length, and travel time.
- Several types of vehicle detectors exist, including ultrasonic, microwave Doppler, microwave true presence, passive (receive only) infrared, active (receive and transmit) infrared, and video detectors.
- Some current applications for vehicle detectors are ramp metering systems, truck-overturning systems, traffic speed maps for the Denver metro-area, and providing vehicle counts along I-70.
- Designers should consider the type of traffic information that needs to be collected and then select the type of vehicle detector that is best suited for the specific site and ITS solution.
- Designers should be aware that specific software is required to interpret the data stream from the detectors and must be integrated into the ITS solution.

FLORIDA DEPARTMENT OF TRANSPORTATION

The Florida Department of Transportation (FDOT) *Plans Preparation Manual* contains the following guidance related to the design and placement of vehicle detection systems, dynamic message signs, and CCTV camera station of FDOT freeways (*4*).

Vehicle Detection Systems

For vehicle detection systems, such as those utilizing video, microwave, magnetic field, or acoustic technologies, the designer should consult with the device manufacturers to ensure that placement and installation plans facilitate proper operation of a particular device type. Be aware of a technology's capabilities and limitations in a given location in order to create a design that is capable of achieving the required levels of detection accuracy.

The clearance requirements for poles, sign structures, field cabinets, and communication hubs for ITS deployments should conform to those provided in FDOT guidelines. Any deviation or alternative or special design must be coordinated with the district design engineer.

Dynamic Message Signs

FDOT defines a DMS as "an electronic sign capable of displaying more than one message, which is changeable manually, by remote control, or by automatic control." (*4*) FDOT uses DMS primarily to advise approaching motorists of roadway and traffic conditions. To satisfy the function, FDOT recommends that designers position the DMS to be legible from the roadway, taking into account the display characteristics of DMS technology (e.g., the vertical and horizontal viewing angles of the LED displays). FDOT permits several types of DMS signs, including walk-in, front-access, or embedded with monochrome (typically amber text), full-color, or tri-color displays. Designers should select the appropriate sign type based upon project-specific needs.

Designers should place DMSs based on the project-specific needs. FDOT provides the following general design criteria to assist designers in determining the proper placement for DMSs:

- A DMS must be able to communicate a meaningful message that can be read and understood by motorists within a brief time period (dictated by the sight distance characteristics of the location and the design features of the sign). This also depends upon the posted speed limit of the roadway. A DMS can display a variety of highway standard fonts and graphics. The DMS design should take into account the message library proposed for use on the project, including text and graphics.
  - For messages displayed on arterial roadways with speed limits of 55 mph or higher and freeways, the minimum character height must be 18 inches.
  - For messages displayed on arterial roadways with speed limits of 45 mph or 50 mph, the minimum character height must be 15 inches.
  - For messages displayed on arterial roadways with speed limits less than 45 mph, the minimum character height must be 12 inches.
- Designers should place DMSs on freeways prior to interchanges that offer alternate routes.
  - DMSs should be place 1 mile in advance of exit approach signing.
  - Designers should maintain a minimum spacing of 800 ft between existing and planned overhead static sign panels and other signs, per the *Manual on Uniform Traffic Control Devices* (MUTCD) (*5*). Designers should consider increased spacing when conditions allow.
  - Designers should maintain a minimum distance of 1450 ft from decision points [meets MUTCD/American Association of State Highway and Transportation Officials (AASHTO) *Green Book* (*6*) requirements].
- When placing a DMS on arterials prior to major intersections that offer alternate routes, designers should place the DMS using the following criteria:
  - The distance in advance of the major intersection should range from ½ mile to 1 mile.
  - At least 600 ft from adjacent signalized intersections.
  - Where the DMS is continuously visible to motorists for at least 600 ft.
  - Where no existing or planned guide signs exist within the 600-ft minimum visibility distance.
  - With minimum interference with adjacent driveways, side streets, or commercial signage.
- Designers should consider placing a DMS in advance of high crash locations and traffic bottlenecks.
- Designers should position the DMS at a location where sufficient space is available between the edge of travel lanes and the right of way limits. The space must be wide

enough to allow the DMS structure to be located within the right of way limits, while meeting the minimum clear zone requirement.

- The placement of a DMS should not conflict with underground or overhead utilities.
- Designers should situate the DMS to accommodate access for service and maintenance vehicles and personnel.
- Designers should place a DMS in advance of all system interchanges.

Closed-Circuit Television Cameras

Closed-circuit television systems consist of roadside cameras, communication devices, as well as camera control and video display equipment at one or more remote monitoring locations that allow surveillance of roadway and traffic conditions. Project-specific needs dictate the placement and overall design of CCTV system. FDOT recommends that designers consider the following the general design criteria when designing and placing CCTV cameras:

- Locate the camera strategically to obtain a complete view of the freeway (keeping all ramps in mind) as well as the arterial traffic.
- Place the camera to view any nearby DMS for message verification.
- Locate the camera to view crossing features (i.e., streets, rail, bridges) as feasible.
- Place the camera structure in accordance with FDOT standards.
- Locate the camera to accommodate access for service and maintenance with minimal to no impact on traffic. For instance, the use of lowering devices to allow cameras to be lowered from the pole top to ground level for servicing with little or no disruption of traffic.

Designs and plans should consider and illustrate camera mounting height. Designers should select mounting height based upon project-specific needs, as well as the following general design criteria:

- Required viewing distance.
- Roadway geometry and lane configuration.
- Roadway classification (i.e., arterial or freeway).
- Life-cycle cost, including maintenance impacts.
- Environmental factors, such as glare from the horizon or from headlights.
- Vertical clearance.

Vehicle Detection and Data Collection

FDOT uses vehicle detectors along roadways to collect traffic information. Data from these detectors are used in the traffic management centers (TMCs) to initiate traffic control measures. FDOT permits the use various kinds of detectors, each of which have unique attributes and limitations.

FDOT specifies the following guidelines for use of vehicle detectors:

- Prepare a design that details a complete detection assembly, including all other necessary components to be supplied and constructed.

- Detail in the drawings the exact location and placement of system components, and include installation details for the required cables.
- Design the cabling installation according to the manufacturer's recommendations.

GEORGIA DEPARTMENT OF TRANSPORTATION

The Georgia Department of Transportation (GDOT) provides the following criteria governing the place, design, and use of changeable message signs (another name for DMS), CCTV, and vehicle detection systems as part of the NaviGAtor system (*7*).

Changeable Message Signs

Changeable message signs (CMSs) allow NaviGAtor system operators to display incident or travel time information to the motorists on the freeways. System operators also use CMSs to communicate incident information (i.e., information related to accidents, stalls, roadwork, or debris) to freeway travelers. Additionally, operators may show information concerning the general condition of downstream traffic, often expressed in travel times, when displaying no other incident message. Operators can also use the CMSs to display AMBER Alerts, evacuation information, or other traffic-related information messages. Messages on the signs may be either operator-generated or automatically created by the NaviGAtor system. A series of database tables allows the instant creation of response plan messages based upon incident data entered by the operators.

Sign placement is very important to the messages that can be displayed on a CMS.

Urban Freeways

For urban freeways, the standard spacing between successive CMSs is generally 5 to 6 miles, though each CMS should be located in advance of major decision points and potential diversion routes. As applicable, designers should consider the location of existing CMSs and roadway geometrics when locating a new CMS. Designers should place the CMS in advance of major decision points and potential diversion routes, so that motorists have sufficient opportunity to:

- Recognize the sign.
- Read the message on the sign.
- Determine their response to the message on the sign.
- Make adjustments (turn signals, lane changes) in response to the message on the sign.

GDOT also recommends that, in urban areas, CMSs should be located as follows:

- A minimum of ⅔ mile in advance of an interchange exit.
- A maximum of 2 miles before decision points or diversion routes, including freeway to freeway interchanges.
- Where the message is legible to motorists 900 ft upstream of the sign location.

The placement of the CMS should facilitate the display of the message to the maximum extent possible.

Urban Arterial Streets and Highways

The use of CMSs on urban arterial streets and highways is usually associated with special event locations, diversion routes for hurricane evacuations, or similar special conditions. Designers should coordinate the location of CMSs with the local agency responsible for traffic operations on the roadway. The visibility requirements listed above are NOT appropriate for arterial streets. The requirements contained in section 2C.05 of the MUTCD should be used as guidelines for sign placement.

Rural

A CMS is warranted in rural areas if it is intended to be used for a specific purpose, such as special event traffic control or a hurricane evacuation route. The designer should make sure the CMS is part of an operational plan by the district and GDOT TMC. The availability of electrical power and communications are the controlling factors in placing rural devices. The specific requirements listed for urban freeways should also be considered in selecting locations for a CMS in a rural area. As with a freeway CMS, designers should place a rural CMS in advance of major decision points and potential diversion routes, so that motorists have sufficient opportunity to recognize, read, respond, and make adjustments as necessary. Designers should seek input from GDOT personnel and gain approval from the assistant state traffic engineer and District Traffic Operations personnel.

Field Location Considerations

There are many considerations designers should address through CMS design. Care should be taken to avoid locating a CMS:

- Within merging/weaving sections.
- Near entrance and exit ramps.
- Within 800 ft (upstream or downstream) of existing or known proposed static sign structures (except for post-mounted signs and median-mounted sequential guide signage).

Closed-Circuit Television System Design

GDOT NaviGAtor operators use CCTV dome cameras for incident verification and general transportation system surveillance purposes. GDOT CCTV cameras can pan, tilt, and zoom by using the NaviGAtor Graphical User Interface (GUI). Cameras are typically located on strain poles at a substantial height to provide the most commanding view of the roadway. GDOT designers should strive to provide as close to 100 percent coverage as is possible for the CCTV camera system. This means that designers should minimize, if not eliminate, blind spots due to bridges, overpasses, signs, billboards, trees, etc.

Urban Freeways

On urban freeways, GDOT locates their CCTV sites after the location of the CMS sites have been determined. The designer should start by locating poles with CCTV cameras (used for general traffic surveillance) at all interchanges within the project limits. GDOT recommends that designers place the CCTV sites in the quadrant of interchange that provides the best freeways views (primary) and the best arterial views (secondary). NaviGAtor operators should be able to use the CCTV cameras at interchanges to monitor the operations of each of the ramp/arterial intersections as well as the queue discharge area of any ramp meters. If a single camera does not have a clear view of all of these locations, then designers should provide a separate CCTV camera for optimal coverage.

GDOT recommends that designers locate CCTV sites between interchanges after placing the vehicle detection systems (GDOT uses both video-based and radar-based vehicle detection systems.). The goal of CCTV camera placement is to achieve 100 percent coverage of the roadway with some overlap in coverage areas of adjacent cameras. If complete coverage cannot be achieved by using the same poles as the vehicle detectors, then GDOT requires that additional poles be added exclusively for the CCTV cameras. Designers should not sacrifice CCTV coverage to co-locate CCTV and vehicle detection systems on the same poles; however, when a conveniently located pole or structure exists, designers may find it to be less costly to use two co-located CCTVs instead of one CCTV on a separate pole by itself.

As a general rule, GDOT places CCTV cameras at 1-mile intervals, preferably on the same poles used for vehicle detection system. Designers should place CCTV cameras all on the same side of the road (it is easier for operators this way). To determine the final location of a CCTV, GDOT recommends that designers consider the following issues:

- A CCTV camera on a curve should be on the outside of the curve so as to maximize viewing distance in each direction.
- Bridges, overhead sign structures, tunnels, vegetation, vertical curves, etc., should not obstruct the view of the CCTV camera. Designers should pay particular attention to the camera view in sag vertical curves. Dome cameras can only pan vertically approximately 2 percent above the horizon.
- Designers should make sure that camera coverage includes the freeway under cross-road overpasses, except where the view of the cross-road is deemed a higher priority.
- NaviGAtor operators should be able to read the face of each CMS using a CCTV camera. Designers should place CCTV cameras 1500 ft from the face of the CMS structure.

GDOT also recommends that designers consider the implications of nearby airports when selecting CCTV camera pole locations. Restricted glide paths for approaching aircraft are sometimes distant from the airport itself. Consequently, the Federal Aviation Administration (FAA) needs to approve pole locations and heights in projects passing near airports. Designers should contact the appropriate airport manager if there is a concern that a pole may be in a runway glide path.

Urban Arterial Streets and Highways

GDOT specifies that designers should locate CCTV sites on arterial streets and highways near signalized intersections to provide coverage of both arterial and intersecting streets. In addition, GDOT guidelines indicate that an arterial CCTV may also be warranted on arterials that are affected by special event traffic or severe weather, such as stream crossings or bridges. While complete corridor coverage is desirable, it may not be feasible due to intersection spacing and roadway alignment. Designers should coordinate with the agency responsible for traffic operations on the roadway to ensure that all locations are accounted for in the design.

Power and communications are usually located along arterial streets and highways. Designers should coordinate pole locations with the local power company or companies in the project area to confirm the power service provider for each location. In addition to utility submissions, design locates should provide additional detail regarding existing underground utilities that could conflict with proposed pole locations. Designers should locate proposed poles to provide a minimum of 10-ft clearance (vertical and horizontal) of overhead power service lines.

If an existing pole is not available for mounting or does not provide adequate height to be effective, designers should locate the proposed new pole within the right of way. If possible, the designer should locate the pole outside of the clear zone to eliminate the need for a guardrail. If the required clear zone is beyond the right of way limits, then the designer should design guardrail or coordinate with the responsible agency to acquire the necessary right of way.

Rural

GDOT may warrant the use of a CCTV station in a rural area if it is intended to be used for a specific purpose, such as special event traffic control or monitoring hurricane evacuation routes. The designer should make sure the CCTV is part of an operational plan by the district and GDOT TMC. Designers should gain approval from the assistant state traffic engineer over ITS Operations and the GDOT district traffic operations personnel.

The final location of CCTV sites on rural roadways depends on availability of suitable power and communications. These sources are normally available at interchanges and crossroads, so this will be the starting point for CCTV locations.

Field Location Considerations

GDOT recommends using overhead sign structures for the mounting of CCTVs where possible. Designers should use tubular extension to mount CCTV cameras to overhead signs structures. Designer should not mount cameras on Type 2 (cantilever) sign structures. Designers should contact the GDOT Office of Bridge Design for approval and allowable length when mounting a tubular extension on an existing sign structure. If a new sign structure is proposed, then a 35-ft tubular extension can be proposed without approval. Designers can often compensate for blind spots caused by sign structures by placing a CCTV camera on the structure.

GDOT requires that designers provide sufficient clearance around the pole or structure base to allow for the following:

- Installation of the side-mount cabinet (Type D).
- Access to both the front and back doors of the side-mount CCTV cabinet.
- Opening of the cabinet doors to at least 90°.
- Personnel to access the cabinet interior from either front or back doors.
- Safe location of a maintenance bucket truck (on shoulder or off pavement so as to not require a lane closure for maintenance).

Although a camera is placed at a certain location to accomplish a transportation management function, a related issue concerns the location of the AC power sources. Designers need to consider the proximity of AC power sources during preliminary design. Careful location of a camera pole can significantly simplify the provision of AC power to the camera(s). Designers should also consider retaining walls, guardrails, or other intervening obstacles between the camera pole and the AC power source. The designer should coordinate with the local service providers to establish the power service points shown on the plans. District Utilities should be kept aware and invited to all meetings between the designer and electrical service providers.

The poles are specified in GDOT Section 639.03.1 Special Provision. The length of the pole is not explicitly called out on the plans. It is up to the contractor to determine the actual length of the pole itself to both achieve the specified mounting height for each device and to have adequate pole depth below the surface.

Vehicle Detection System Design

Detection systems are specified in the GDOT Section 937 Special Provision, which includes details for equipment included in the cabinet. GDOT used two types of detection systems: video detection systems and microwave radar detection systems. Both systems provide presence detection, vehicle counts, roadway occupancy, classification, and speed information to the Department's NaviGAtor Intelligent Transportation System.

Urban Freeways

GDOT recommends that designers comply with the following steps when designing and placing a vehicle detection system:

1. Familiarize yourself with the GDOT's ITS Strategic Deployment Plan.
    - Determine level of deployment for the freeway.
    - Follow spacing criteria specified for each deployment level.
    - The absolute maximum should only be used in extreme cases where the placement of vehicle detector poles is impossible within the normal design ranges due to obstructions or steep slopes in the field. Meeting the spacing criteria will ensure that NaviGAtor obtains accurate data while utilizing existing sign structures, and one pole for the vehicle detectors and CCTV cameras will reduce construction costs.
2. Pick one direction (northbound/eastbound or southbound/westbound) to work on at a time.
3. Identify elements that may control the location of vehicle detection sites.
    - If the new project is adjacent to an existing NaviGAtor coverage area, then first note the location of the last existing vehicle detectors. This will allow the designer to maintain optimal spacing when transitioning from existing to proposed devices.
    - Note the location of the CCTV poles that you consider fixed at this point, such as CCTV cameras located within interchanges or at key cross streets.
    - Note the location of CMS and mark an area 1500 ft in front of the CMS where you need to locate a CCTV. You want to co-locate the vehicle detection system on these CCTV poles if possible.
    - Note full-span truss-type sign structures. Constructing a tubular extension to mount a video-based vehicle detection camera on an existing sign structure costs much less than

using a new pole. For radar-based vehicle detectors, these structures may be used for forward mounting radar or for side fire mounting. Do not mount a radar-based vehicle detector on a CMS sign structure as the interference caused by the large amount of metal in the structure assembly often reduces the accuracy of the radar-based vehicle detector.

4. Locate the ramp/mainline vehicle detection system detector first.
   - It is desirable to have detection on each ramp at an interchange, and typically these poles become key control points in your layout, so locate them first. These poles should have vehicle detection systems for both the mainline and the ramp, as separate poles for ramp coverage only are generally not installed.
   - Vehicle detection systems on ramps should be located so they capture traffic just as it enters or leaves the freeway. Care should be taken so that the detection zone is not in an area where traffic is waiting in a ramp meter line.
5. Fill in the detection system between the systems located at the interchanges. It is desirable to have at least one detection system in each direction of travel between interchanges. Accomplish this by following the spacing criteria presented in Step 1, and then adjust to take advantage of any existing CCTV poles or sign structures that you identified in Step 3. Ensure the spacing criteria are met.
6. Other considerations:
   - Freeway-to-freeway interchanges place additional restrictions on detection locations, because the vicinities of merge and diverge points are often locations where traffic is not free-flowing. Consequently, detection systems should not be located less than 700 ft upstream of a diverge location or downstream of a merge location.
   - Place no more than four video-based detection cameras or radar-based vehicle detector units and one CCTV camera on a single pole.
   - The maximum number of lanes to be monitored is seven lanes plus two shoulders. Do not design for coverage of more lanes with a single system.
   - Vehicle detectors should be placed off the right shoulder of the highway for detection of travel lanes nearest to the pole. Detection systems should not be placed to detect travel lanes across the median/barrier wall (i.e., in the opposite direction of travel), because of occlusion by the median wall and tall vehicles, and parallax distortion will degrade the quality of detection. On narrow-median roadway configurations, such as two lanes in each direction separated by a median barrier wall, it may be possible to detect traffic across a median wall.

Urban Arterial Streets and Highways

The preferred location for detection is where free-flowing traffic is common and where traffic flow breakdowns are less likely to occur. Typical spacing for detection installations is approximately ½ to 1 mile. Designers should coordinate with the local agency (typically the county/city DOT) responsible for traffic operations on the roadway.

MINNESOTA DEPARTMENT OF TRANSPORTATION

The *Mn/DOT Intelligent Transportation System (ITS) Design Manual* provides warrants for installing dynamic message signs. These warrants are from the ENTERPRISE pooled fund project (*8*). As part of the ENTERPRISE research project, warrants were developed for dynamic message signs, closed-circuit television, highway advisory radios, and roadway weather Information systems. These are not official warrants but can be used as guidance toward the determination of ITS components.

DMS Warrant

For dynamic message sign devices, eight warrants have been identified to capture the most common uses of this device. While there are other purposes and uses for DMS, the warrants developed to date have focused on the following eight:

- DMS Warrant – 1: To Inform Travelers of Weather Conditions.
- DMS Warrant – 2: To Inform Travelers of Traffic Conditions.
- DMS Warrant – 3: Changing Traffic Conditions.
- DMS Warrant – 4: Special Events.
- DMS Warrant – 5: Parking Availability.
- DMS Warrant – 6: Transit Park-and-Ride Lot Availability.
- DMS Warrant – 7: Evacuation Routes.
- DMS Warrant – 8: Jurisdictional Information.

DMS Warrant – 1: To Inform Travelers of Weather Conditions

Purpose: To provide road weather information to drivers so that the drivers can choose to continue travel on the route or to adjust their speed, route of travel, or divert from the trip in anticipation of an upcoming weather hazard.

Device is warranted if:

1. The location is prone to weather situations that travelers would not otherwise be forewarned about (e.g., spots where fog regularly forms, bridges that ice early, mountain passes with weather that differs from approaches), ***and***
2. There is available road weather information for the area downstream of the candidate DMS location, ***and***
3. There is the capability (either manually by staff members or automated through a condition reporting system) to create event-specific descriptions of weather conditions to be displayed on the DMS, ***and***

4a. There is a need to disseminate event-specific descriptions (rather than a lower technology approach such as activating a flashing warning sign that says "Weather Alert When Flashing"), ***or***

4b. There are options for either alternate routes or services that might be described on the DMS, where travelers may wait out conditions, ***or***

4c. Flashing beacon signs have been tried and not proven to generate responses from travelers, ***and***

5. Weather events contribute to a significant number of crashes or road closures such that there are major impacts to travelers (this may include one or more annual closures or crashes on a freeway or 10 or more crashes or closures on arterials).

Warrant Advice: If the only warrant met for a DMS is the weather information warrant, then it is recommended that the lesser technologies are considered before deploying full DMS capabilities.

Partial Warrant Criteria: If either #1 or #5 above is met, the warrant is considered 'Partially Met.' If one or more additional purposes are partially met at this location for this device, the device shall be considered 'Warranted.'

DMS Warrant – 2: To Inform Travelers of Traffic Conditions

Purpose: To provide current traffic status information (incidents, congestion, travel time, road work) to drivers so that drivers can choose to divert to avoid the situation, to reduce driver anxiety, and to reduce crashes involving drivers encountering unexpected stopped traffic.

Device is warranted if:

1. There is a reliable, real-time source for status information for the target area, ***and***
2. The area encounters events that unexpectedly stop traffic an average of at least two times per month, ***and***

3a. There are acceptable alternate routes with adequate capacity to accept vehicles that may deviate based upon the information, ***or***

3b. The location is a stretch of road where no alternate routes are possible and travelers would benefit from information describing the cause and/or extent of delays in order to relieve driver anxiety or confusion, ***and***

4. There are horizontal or vertical curves that create safety issues when traffic is stopped unexpectedly, ***and***
5. The route being considered for the DMS has on average at least two hours of peak period travel where traffic flow exceeds 1100 veh/hour/lane or experiences conditions considered Level of Service C.

Partial Warrant Criteria: If #2 above is met, the warrant is considered 'Partially Met.' If one or more additional purposes are partially met at this location for this device, the device shall be considered 'Warranted.'

DMS Warrant – 3: Changing Traffic Conditions

Purpose: To notify drivers in advance of special changing traffic conditions and roadway configuration changes associated with road construction or maintenance in order to reduce driver confusion that could result in a crash.

Device is warranted if:

1. The candidate location is upstream of an area with construction or maintenance activities that are expected to cause at least 15 minutes of delay to the mainline traffic, ***and***
2. The candidate location is upstream of traffic control or construction/maintenance activities that are expected to change more frequently than once every 60 days, ***and***
3. The speed limit is greater than 45 mph.

Notes:

A. If question #2 is not met (activities do not change frequently), lower cost static signage is recommended.
B. Portable DMS vs. permanent DMS should be considered based on the expected duration of events impacting the area.

Partial Warrant Criteria: If #2 above is met, the warrant is considered 'Partially Met.' If one or more additional purposes are partially met at this location for this device, the device shall be considered 'Warranted.'

DMS Warrant – 4: Special Events

Purpose: To provide parking or alternate route information about special events or major venues to drivers in order to reduce congestion and delays due to unnecessary "circling the block" or non-participating drivers being caught in traffic.

Device is warranted if:

1. The location contains a venue that houses ticketed events (typically with rapid and tight arrival patterns for a specified start time), ***and***
2a. The event venue typically houses at least two weekday (Monday–Friday) ticketed events per week (including seasonal sporting events that only occur during the season), ***or***
2b. The event venue typically houses at least 10 events per year attracting 30,000 visitors or more, ***and***
3. The setting of the venue is such that mainline traffic (not attending the event) is impacted by the conditions at least once per week, ***and***
4. There are alternate parking or traffic options that could be displayed on signs to direct visitors to more preferred options.

Warrant Advice: Placement of DMS signs should consider the intent of each sign. For example, further upstream signs are more effective at helping non-visitors to the venue avoid traffic congestion while signs closer to the venue are effective for directing drivers to open capacity.

Partial Warrant Criteria: If #1 and either #2a or #2b above are met, the warrant is considered 'Partially Met.' If one or more additional purposes are partially met at this location for this device, the device shall be considered 'Warranted.'

DMS Warrant – 5: Parking Availability

Purpose: To provide real-time parking availability information to drivers to avoid unnecessary "circling the block" looking for parking spots.

Device is warranted if:

1. The area contains ample parking to handle the regular visitors, either during commuter periods or special events, ***and***
2. The area contains a set of similar parking garages (similar parking costs) each with generally comparable ingress and egress and access to events (i.e., parking facilities are all generally equal options to select from), ***and***
3. Visitors regularly are unable to find parking, and 'circling the block' occurs for more than 15 minutes during the AM commuter period or prior to special events, as visitors seek out parking spaces.

Partial Warrant Criteria: No partial warrants are identified for this purpose.

DMS Warrant – 6: Transit Park-and-Ride Lot Availability

Purpose: To provide real-time parking availability information to drivers regarding transit park-and-ride lots.

Device is warranted if:

1. The area contains park-and-ride lots that fill to capacity on either a regular basis or during regularly occurring events (e.g., inclement weather, sporting events), ***and***
2. Alternate park-and-ride lots are available (either upstream or downstream) that do not typically fill to capacity, ***and***
3. There is the capability (or willingness) to monitor park-and-ride facilities for available spaces.

Partial Warrant Criteria: No partial warrants are identified for this purpose.

DMS Warrant – 7: Evacuation Routes

Purpose: To provide evacuation route information to drivers during disaster or homeland security events.

Device is warranted if:

1. The area is a major metropolitan area or has nearby icons that increase the likelihood of requiring an evacuation (e.g., nuclear reactor, major attraction), ***and***
2. The area evacuation procedures allow for traffic movements and/or the use of roads that otherwise are not available to the public (e.g., contra-flow lanes).

Partial Warrant Criteria: If #2 above is met, the warrant is considered 'Partially Met.' If one or more additional purposes are partially met at this location for this device, the device shall be considered 'Warranted.'

DMS Warrant – 8: Jurisdictional Information

Purpose: To provide jurisdictional specific information to drivers at or near borders between two jurisdictions.

Device is warranted if:

1. There are differing rules or regulations between adjacent jurisdictions, ***and***
2a. Display of differing rules or regulations on static signs would either not attract enough attention, ***Or***
2b. The rules or regulations change frequently (e.g., load restrictions).

Partial Warrant Criteria: If #1 above is met, the warrant is considered 'Partially Met.' If one or more additional purposes are partially met at this location for this device, the device shall be considered 'Warranted.'

CCTV Warrant

For closed-circuit television devices, MnDOT uses five warrants to capture the most common uses of this device. While there are other purposes and uses for CCTV, the warrants developed to date have focused on the following five:

- CCTV Warrant – 1: Traffic Observation.
- CCTV Warrant – 2: Traffic Incident or Event Verification.
- CCTV Warrant – 3: Weather Verification.
- CCTV Warrant – 4: Traveler Information.
- CCTV Warrant – 5: Field Device Verification.

CCTV Warrant – 1: Traffic Observation

Purpose: To visually observe traffic conditions in order to determine if alternate signal timings are appropriate before implementing alternate traffic signal timing plans remotely.

Device is warranted if:

1. There are typically periods of time at least twice per week of 'loaded' cycles (i.e., where the vehicles in the queue do not all dissipate in one green cycle) that last 15 minutes or longer, ***and***
2. The signalized intersection has sufficient cross street traffic such that visual observation is needed determining if alternate signal timings are appropriate to benefit the primary direction of flow (i.e., in order to verify that the secondary street is not backing up), ***and***
3. Pre-timed flush plans exist and if local policy would only allow implementation of flush timing plans with visual observation verifying the need.

Partial Warrant Criteria: If either #1 or #3 above is met, the warrant is considered 'Partially Met.' If one or more additional purposes are partially met at this location for this device, the device shall be considered 'Warranted.'

CCTV Warrant – 2: Traffic Incident or Event Verification

Purpose: To allow traffic operations personnel or emergency response teams to visually verify traffic flow and/or incidents (e.g., crashes, debris in roadway) in order to activate or dispatch appropriate response and post messages to traveler information systems.

Device is warranted if:

1. The candidate location would allow visual verification of incidents, queues, or other events within an area that encounters incidents as frequently as twice per month for arterial streets or once per month for freeways, ***and***

2a. The incidents and events that occur on freeways typically cause delay to travelers of at least 15 minutes while the incident is active and has not been cleared, ***or***

2b. The incidents and events that occur on arterials typically cause impact travel such that the signal progression is no longer occurring and vehicles are not clearing green cycles, ***and***

3. The location encounters at least two hours per day of peak period travel where traffic flow exceeds 1100 veh/hr/lane; or conditions considered Level of Service C; or AADT) of 16,800 for a 2-lane road; 33,600 for a 4-lane road; 50,400 for a 6-lane road; 67,200 for an 8-lane road.

CCTV Warrant – 3: Weather Verification

Purpose: To allow maintenance dispatchers and traffic control personnel to verify weather conditions on the roadway, either to guide traveler information dissemination or to dispatch snow removal and treatment operations.

Device is warranted if:

1. The location typically encounters at least 10 winter weather events each season, ***and***
2. Winter weather events have a significant impact to travelers at this location (due to such circumstances as either: local terrain, lack of alternate routes, winding or steep routes), and it is a location that travelers are frequently concerned about, ***and***
3. There are no nearby weather sensors reporting accurate and real-time conditions such as visibility, precipitation, or pavement temperatures, and if nearby weather sensors would be enhanced through the capability of visual observation.

Partial Warrant Criteria: If #1 and #3 above are met, the warrant is considered 'Partially Met.' If one or more additional purposes are partially met at this location for this device, the device shall be considered 'Warranted.'

CCTV Warrant – 4: Traveler Information

Purpose: To allow travelers to understand traffic delay and road weather conditions by viewing images of the roadway from the Internet prior to departing.

Device is warranted if:

1a. The location visible by the camera image has a history of congestion on a regular basis (i.e., each commuter day is a candidate for congestion), ***or***
1b. The location visible by the camera is prone to weather situations that travelers would not otherwise be forewarned about (e.g., spots where fog regularly forms, bridges that ice early, mountain passes with weather that differs from approaches), ***or***
1c. The location visible by the camera image is a remote area that receives considerable traffic volume due to commercial vehicle traffic or recreational traffic, ***and***
2. The majority of travelers to the area have Internet access in proximity to the area where camera images are of value to travelers prior to departure.

Partial Warrant Criteria: If #1a, #1b, or #1c above is met, the warrant is considered 'Partially Met.' If one or more additional purposes are partially met at this location for this device, the device shall be considered 'Warranted.'

CCTV Warrant – 5: Field Device Verification

Purpose: To allow traffic or maintenance operations personnel to verify operational functionality of in-field devices (such as dynamic message signs, road/lane closure gates, and other devices).

Device is warranted if:

1. The field device visible by the candidate camera location displays critical messages or is critical to where visual verification is needed, ***and***
2. The field device visible by the candidate camera location has a history of not responding to remote access, ***or***
3. The camera operation would prevent unnecessary trips to verify functionality of the field device.

Warrant Criteria: If #1 and #2 above are met, or if #3 above is met, the warrant is considered 'Warranted.' If one or more additional purposes are partially met at this location for this device, the device shall be considered 'Warranted.'

OREGON DEPARTMENT OF TRANSPORTATION

The Oregon Department of Transportation (ODOT) *Guidelines for the Operation of Variable Message Signs on State Highways* (*9*) provides the following guidance and criteria related to the installation of variable message signs in freeways in Oregon.

Authority

Under Oregon Revised Statute 810.200, *Uniform Standards for Traffic Control Devices; Uniform System of Marking and Signing Highways and Letters of Authority from the Oregon Transportation Commission*, the state traffic engineer is responsible for exercising authority with respect to the use of traffic control devices, including VMS.

Installation and location of VMS on state highways requires the approval of the state traffic engineer. The display of public service messages on VMS also requires the approval of the state traffic engineer. Each region traffic engineer or traffic engineer approves non-standard messages other than public service messages in his or her region.

VMS Approval Process

The state traffic engineer must approve all permanent VMS installations prior to the project approval and inclusion in the Statewide Transportation Improvement Program (STIP).

The region traffic engineer, working with Project Teams and the ITS Unit, should prepare a request for approval of a new VMS and submit it to the state traffic engineer. The request should include:

- Specific information regarding the purpose of the sign (who for, type of messages, why needed at the desired location).
- Proposed type of sign and support.
- Desired location, and operational responsibilities.

If an area-wide transportation management study has been completed that includes the proposed VMS, a copy should be included with the request.

VMS Site Considerations

Permanent VMS sites are selected according to the intended need and available, suitable locations. ODOT requirements specify that designers coordinate with the ITS Unit and the Region Traffic office when new signs are being considered. The following factors should be considered when installing permanent changeable message signs:

- Locate upstream of known bottlenecks and high crash locations.
- Locate upstream of major diversion decision points, such as interchanges.
- Avoid locating within an interchange except for toll plazas and managed lanes.
- Avoid locations where the information load on drivers is already high due to guide signs and other types of information.
- Avoid locations where drivers frequently perform lane-changing maneuvers in response to static guide sign information, or because of merging or weaving conditions.

PENNSYLVANIA DEPARTMENT OF TRANSPORTATION

Guidance and criteria on the use, placement, and design of CCTV, DMS, and vehicle detection systems is provided in The Pennsylvania Department of Transportation (PennDOT) *Intelligent Transportation System Design Guide* (*10*) The following is a brief summary of these requirements.

Closed-Circuit Television

PennDOT states that the primary function of the closed-circuit television camera is to provide surveillance of the transportation system and enhance situational awareness. CCTVs enable

Department Operations staff to perform a number of valuable monitoring, detection, verification, and response activities including the following:

- Detecting and verifying incidents.
- Monitoring traffic conditions.
- Monitoring incident response and clearance.
- Verifying message displays on dynamic message signs.
- Assisting emergency responders.
- Monitoring environmental conditions (visibility distance, wet pavements, etc.).
- Monitoring assets (Homeland Security).

To maximize the effectiveness of a CCTV camera and to reduce potential threats to driver safety, PennDOT recommends that designers carefully consider the camera type and location when deploying any new camera. Designers should first consider the operational requirements of the camera. This will determine the camera type and the general camera location required to achieve those requirements. These two factors determine the mounting structure characteristics that are needed.

Location/Placement Guidelines

PennDOT's criteria for selecting CCTV camera locations are based on the operational and maintenance requirements. The desired coverage will often dictate the general camera locations. This should be a primary design consideration. Local topography will also play a major role.

PennDOT guidelines indicate that camera locations should provide a clear line of sight with minimal obstructions. Table 2 below provides a summary of the factors that designers should be taken into account when selecting the site and placement of the camera.

Table 2. PennDOT's Camera Site Selection and Placement Considerations.

Camera Site Selection and Placement Considerations	
Visibility	• Cameras in low light conditions, such as tunnels, should be located so that the main view is away from bright light. • Near horizontal curves, install on outside of curve. • Near vertical curves, install at the crest. • At the intersection of two major routes or an interchange, place CCTV so that secondary roads can also be monitored. • The blind spot created from the pole should be oriented at a location non-critical to viewing.
Utility Availability	• Consider proximity to power and communications. • If fiber optic communication is available, try to place the camera on the same side of the roadway to eliminate lateral crossings (this is secondary to visibility regulations).
Safety and Device Protection	• Protect CCTV structure with guiderail inside the clear zone, but consider lateral deflection and maintenance vehicle access. • Medians are not the preferred location, but wide medians may be considered if suitable roadside locations are not available. • To reduce site erosion, reduce construction costs, and provide longer device structure life, avoid locating the structure on sections that have a fill slope of greater than one vertical to three horizontal.
Operational Considerations	• Install at locations with recurring congestion and other high volume areas. • Install at locations known to have adverse weather conditions. • Install at locations with recurring crashes. • If possible, position cameras to view nearby dynamic message signs for message verification. • Large interchanges of two major freeways may require more than one camera to obtain all desired views of roadways and ramps. • If possible, avoid mounting onto bridge structures due to the potential of vibration affecting the image.
Maintenance Considerations	• Where possible, the CCTV should be located such that a maintenance vehicle can park in the immediate vicinity, without necessitating a lane closure or blocking traffic, when possible. • A concrete maintainer pad in front of the enclosure opening should be provided per Pub 647M. • The CCTV cabinet should be mounted away from traffic so that the maintainer is facing traffic when looking at the cabinet. This will increase the life of the filter as well as the safety of the maintainer.

Urban vs. Rural

In urban areas, PennDOT considers full camera coverage to be full build. PennDOT considers full camera coverage of a roadway to be when the resulting CCTV camera placements allow an operator to view and monitor the entire corridor with no breaks. Full build out is warranted on certain roadways in urban areas, given the high usage of the roadway. In order to provide full and continuous coverage of a roadway (subject to the operational requirements), cameras should be placed no more than one mile apart depending on the curvature of the roadway.

In rural areas, full build out does not require continuous camera coverage. In rural areas, CCTV camera coverage is typically preferred at interchanges of limited access roadways (interstate-to-interstate or interstate-to-major limited access) or at interchanges with highly traveled arterials. Other considerations besides high traffic volumes may be justification for full camera coverage in rural areas. Full camera coverage may be implemented on a case-by-case basis where coverage could be useful, such as a segment that experiences high winds, excessive ice, or some other sort of extreme weather.

The definitions of urban and rural areas are established by the Bureau of Planning and Research (BPR) 2009 Highway Statistics, and are as follows (*11*):

- Urban Area – Urban places of 5000 or more population and urbanized areas as designated by the Bureau of Census.
- Small Urban Area – Places having a population of 5000 or more, not in an urbanized area.
- Rural – The area outside the boundaries of small urban and urbanized areas.

Dynamic Message Signs

For PennDOT, the primary function of the dynamic message sign is to provide traveler information. While the nature of this information may vary, the goal is to disseminate roadway condition information to travelers so that they can make informed decisions regarding their intended trip and/or route.

PennDOT guidelines require that DMS be used in accordance with the *Dynamic Message Sign (DMS) Operating Guidelines* (*12*) document published by PennDOT. Some typical DMS uses include notifying travelers of:

- Full road closure.
- Lane closures (incident, maintenance/construction, events, etc.).
- Weather/road conditions.
- AMBER Alerts.
- Special events.
- Travel times (automated, real-time).
- Future road work.
- Scheduled safety messages [formerly public service announcements (PSAs)].
- Sign testing.

To maximize the effectiveness of a DMS and to reduce potential threats to driver safety, the sign type, placement, and the supporting structure must all be carefully considered when designing and deploying any new sign. First, the operational requirements of what purpose the sign will satisfy must be considered. This will determine the general location and the type of sign. These operational requirements and the location will determine the required support structure.

The site characteristics in the vicinity of the planned DMS must be investigated. These characteristics dictate the amount of information that can be displayed. Relevant characteristics include:

- Operating speed of the roadway.
- Presence and characteristics of any vertical curves affecting sight distance.
- Presence of horizontal curves and obstructions such as trees or bridge abutments that constrain sight distance to the DMS around the curve.
- Location of the DMS relative to the position of the sun (for daytime conditions).
- Presence, number, and information on static guide signs in the vicinity.
- Frequency of fog that may reduce visibility of the sign.

Vehicle Detection Systems

Vehicle detection systems are standalone point detectors that detect the presence of vehicles and their characteristics. They can detect and provide valuable real-time and historical data, including speed, volumes, vehicle presence, occupancy, gaps, and incident occurrence. The department can then utilize these data to complete a variety of functions, including:

- Real-time traffic and incident management.
- Traveler information.
- Historical analysis.
- Origin destination information.
- Roadway capacity analysis.
- Performance measures.
- Planning and design purposes.

Detectors are used for two primary purposes: data collection and incident detection.

Data Collection

Vehicle detectors for data collection are deployed in two methods:

- Single Point Detection – Deployed at specific points along the roadway to gather and store data such as vehicle volumes, speeds, and occupancy. This is the most common video detection system deployment.
- Roadway Corridor Detection – Deployed along whole corridors to gather data such as vehicle volumes and speeds. These data are used to generate maps or other graphical representations of corridor speeds, typically called speed maps.

Incident Detection

Incident detection is a traffic management function that provides automated alarms and notifications of potential incidents to TMC operators. These systems require vehicle detectors at regular intervals along a corridor that have the capability to detect vehicle presence, volume, and speeds. The detector data are then fed to a software program that employs an algorithm to determine the presence of an incident on the roadway.

VIRGINIA DEPARTMENT OF TRANSPORTATION

VDOT Northern Region Operation's (NRO) vision for CCTV camera operations is provided below: (*13*).

> *The VDOT Northern Region Operations Closed Circuit Television (CCTV) Camera System will provide Traffic Management Center (TMC) operators with the ability to detect incidents, verify incident information, and monitor traffic conditions on VDOT roadways. CCTV images will be shared with regional and statewide stakeholders to improve interagency coordination. Additionally video images depicting real-time roadway conditions will be available to the motoring public.*

The system envisioned in VDOT's Concept of Operations combines upgrades to the existing system's camera and communications equipment, camera infill within the existing system's covered corridors, and installation of new field equipment to expand coverage to new areas within the region. The system also includes new system control, both in terms of new control software and a new TMC.

The new CCTV system should enhance the benefits that the existing CCTV infrastructure provides its users while providing adequate coverage to new key areas through expansion. The system should use CCTV technology's full potential for gathering and distributing real-time visual information about remote locations to empower operators to practice corridor management of freeways and alternate routes. The CCTV system will be an integral part of the regional ITS network operated through a combination of automated control by Advanced Traffic Management System (ATMS) software and human operators at the Public Safety Transportation Operations Center (PSTOC) TMC.

Freeway Operations staff uses the CCTV system to detect and verify freeway incidents such as accidents, breakdowns, and debris on the roadway as well as to monitor planned and unplanned events such as lane closures for road work. Freeway Operations staff needs to be able to verify the performance of other ITS systems using the CCTV system. The Freeway Operations staff needs the system to help increase operator efficiency through a video incident detection (VID) expert system to notify operators of road condition changes in a camera's feed while another feed is being viewed.

Maintenance

Maintenance needs to be able to restore system functionality as quickly and easily as possible in order to provide for other users' needs to be met. A system that has minimal cost and downtime when serviced will also help the maintenance department to effectively steward its budgetary and labor resources.

CCTV availability can be measured by the equipment's mean time before failure (MTBF). When equipment does fail, the mean outage duration, measured as the mean time to repair (MTTR), will also be an indicator of maintenance performance and CCTV availability.

The number of maintenance personnel trips to service cameras, along with travel time and time on-site, can all be tracked as performance measures of system maintenance needs. These measurements will show the system's demand on the maintenance staff and budget.

Cameras

As per the VDOT NRO's Go Forward Plan, CCTV camera images should allow for operators to detect and verify events, verify status of other ITS devices, and provide information on traffic conditions to the public and the media. CCTV cameras should be added on arterials adjacent to key highways to monitor their traffic conditions and make informed diversion decisions. The cameras should be placed so that there are no major coverage gaps for either direction's traffic. In addition, views of all dynamic message signs and high-occupancy vehicle (HOV) lane gates should be incorporated within the CCTV coverage in accordance with the VDOT NRO DMS Concept of Operations and FHWA funding guidelines for DMS. All CCTV cameras will be equipped with standards-based (i.e., MPEG-4, H.264, or equivalent) IP-formatted digital encoding with images able to be distributed via high speed communications and compatible with the new ATMS. Existing cameras will be upgraded and replaced as funding or device failures warrant. The camera images should continue to be shared with regional stakeholders and the general public through VDOT's existing Video Clearinghouse for traffic incident and condition information dissemination, TrafficLand, or its successor(s). In an effort to automate the incident detection process, VID expert systems may be incorporated at strategic locations to support incident management, as well as to further maximize the ratio of cameras to TMC operators.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

Washington State Department of Transportation (WsDOT) *Intelligent Transportation Systems (ITS) Design Guide* (*14*) provides the following guidance related to vehicle detection stations, DMSs, and CCTV.

Data Stations

WsDOT's criteria indicate that data stations are generally placed at ½-mile intervals between interchanges. Intervals of more than ½ mile allow more traffic pattern fluctuations to go undetected.

The data station controller cabinet is situated along the freeway mainline adjacent to corresponding roadway detection loops. Where ramp control is implemented, ramp meters are installed at on-ramp locations. In areas where ramp meters are anticipated in the future, data stations should be placed near ramps then converted to ramp meters when the need arises.

Closed-Circuit Television

WsDOT guidelines indicate that finding the correct location for CCTV is extremely important. Designer should locate CCTV cameras to provide a clear line of sight with minimal obstructions.

For low light environments (such as tunnels and parking garages), CCTV cameras should be placed so that the main view is looking away from bright light. Looking into bright light from a low light condition causes washout of the video image. In the case of a tunnel camera, the first camera would ideally be located at the tunnel entrance facing into the tunnel.

WsDOT's spacing guidance requires that CCTV be located along the highway at a maximum distance of 1 mile between cameras. Occasionally, this one-mile spacing may be increased (such as for a long, straight stretch of highway with unobstructed views) with the use of a doubler. A doubler is a second lens used to double the magnification at the expense of light levels entering the cameras and focus quality.

Furthermore, WsDOT typically locates a camera at each interchange. This allows WsDOT operators to monitor the ramp metering as well as ramp queues. WsDOT also recommends that a minimum of two cameras be placed at freeway-to-freeway interchanges (one to monitor each freeway).

WsDOT also requires that, where feasible, cameras be located so that the message of an adjacent variable message sign can be read. This allows WsDOT operators to provide visual verification of VMS status.

The design guidelines state that the best camera location is often on or next to an under crossing because of the increased altitude over the roadway or view of an interchange. If possible, the camera should be located off of a bridge structure because vibration of the bridge can have an effect on image reliability (usually this effect is minimal). Often, however, because of obstructions such as trees, the bridge structure will clearly be the best place to install the camera. Headquarters Bridge Department must design a suitable foundation for this camera pole. Ideally, this pole would be located above a bridge column or bent to reduce vibration. Headquarters Bridge Department should be notified early on in Plans, Specification, and Estimates (PS&E) if a bridge will be affected.

A less desirable alternative to bridge placement is to place the camera adjacent to the roadway, a maximum of 10 ft from the bridge structure and extending a minimum of 30 ft above the top of the under crossing. The camera may then be serviced from the roadway on top of the under crossing.

Dynamic Message Signs

The ideal location for a DMS is on a minimum 800-ft section of straight roadway, since the motorist must pay more attention to the road when negotiating a horizontal curve. Permanent VMS should be mounted over a freeway, on a structure or sign bridge.

Sign spacing is also important in DMS visibility. Sign spacing for a DMS should be per the MUTCD.

The brighter fiber optic/flip disk hybrid should be specified when the south, east, or west sky is visible behind the sign. The LED/flip disk hybrid is more suited for applications where the north, or no sky, is visible behind the sign.

CHAPTER 3. TXDOT CURRENT POLICIES, AND PRACTICES FOR INSTALLING, REPAIRING, AND REMOVING ITS DEVICES

The TTI research team examined the current policies and practices employed by various TxDOT districts to warrant the installation, repair, and removal of ITS devices and systems. Several districts that have deployed ITS devices were contacted as part of this task and asked to provide information related to their policies and practices concerning the following:

- Formal guidelines, criteria, and procedures used to justify the installation, replacement, and/or removal of ITS devices (specifically CCTV camera systems, traffic sensor equipment, or dynamic message signs).
- Processes and procedures used to assess and monitor the health of the ITS devices deployed in their district.
- Processes and procedures for collecting data used in making equipment procurement, deployment, and replacement decisions.
- Types of decision support tools and recordkeeping systems (such as asset management systems and/or inventory management systems) used to assist in the decision-making process.

In addition, each district was asked to provide any forms, procedures, or decision support tools that they may have developed to assess whether to install, replace, repair, or decommission ITS field devices.

Representatives from the following TxDOT districts provided information used in this assessment:

- Houston.
- El Paso.
- Fort Worth.
- Austin.
- Dallas.

Following is a summary of the findings of these interviews. Individual districts have not been identified in the discussion of the results to preserve anonymity of the respondents.

INSTALLATION/REPLACEMENT/REMOVAL CRITERIA

While none of the TxDOT districts reported having "formal" guidelines, criteria, or warrants for determining when and/or where to install, replace, or remove ITS field devices, most respondents reported that they use "informal" criteria in their districts. These "rules of thumb" criteria generally follow national standard operating practices. Examples include the following:

- Dynamic message signs are typically located to the side of the travel lanes in advance of driver decision points (e.g., major interchanges or detour points for incidents). DMSs should have clear line of sight, away from curves, and be located a minimum distance from other fixed signs).

- Cameras are spaced about every ¾ –1 mile in urban areas, with spacing increasing in less densely populated areas.
- Roadway sensors/detection stations are spaced at regular intervals on the mainlanes, generally between exit ramps. Most districts use microwave detectors as their primary detection technology; however, several districts have deployed and are considering deploying Bluetooth ™ technologies to provide measurement of travel times.

Few districts reported having formal processes or criteria for determining when to replace ITS field devices. Most districts decide to replace field devices when one or more of the following occur:

- When multiple failures of components/parts occur.
- When repair/replacement parts for devices are no longer available.
- When devices become obsolete.
- When opportunities exist to replace/update equipment as part of a roadway construction project.

Few districts reported removing already deployed field devices. One district reported removing a DMS after switching technologies (i.e., going to an LED-based sign). This district found the viewing angle to the sign to be less than desirable, and the sign was taken out and not replaced. This issue was related to the original design (non-optimal placement of the sign) and not the technology itself.

Several of the districts reported that they were in the process of phasing out their lane control signals. At least one district cited that the cost to maintain these little-used devices was a factor for deciding to decommission their use. However, House Bill No. 2204 permits the Texas Transportation Commission to establish variable speed limits (VSL) on Texas highways. VSL is one of the active traffic management (ATM) strategies. If VSL is proven successful in Texas, other ATM strategies such as hard shoulder running will likely receive more widespread deployment in the future. Lane control signal would be an important component for implementing hard shoulder running.

HEALTH MONITORING OF FIELD DEVICES

Most districts use their TMC operator interface systems to monitor the health of their devices. Through map interfaces, TMC operators can quickly determine the status of individual devices. The Lonestar™ Advanced Traffic Management System software system provides user interfaces (UIs) that allow the operators to monitor the status of most field devices, including DMSs, lane control signals, traffic sensors, travel time links, and CCTV cameras.

Most districts reported having only basic maintenance capabilities for ITS field equipment. TMC operators have the ability to determine the source of many operational issues (i.e., bad cameras, failed switches, malfunctioning radios, etc.). District maintenance technicians work with TMC operators to perform an initial diagnosis of the failure to determine if the device can be repaired by district personnel or if a maintenance contractor needs to be called. Several of the districts reported using maintenance contracts to perform their routine maintenance on ITS field. Generally, these contractors are responsible for repairing, replacing, or removing all ITS field devices (up to the field communication switches). District or Division staff is responsible for repairs to networking equipment and TMC software support.

There does not appear to be any statewide guidelines on routine maintenance. Each district appears to follow their own schedule for performing routine or preventative maintenance, with the most visible ITS items receiving the most attention. Districts often prioritize maintenance needs based on funding availability and importance of corridor rather than importance of devices.

LIFE CYCLES OF SYSTEM COMPONENTS

Most districts reported that the majority of their ITS equipment was approaching its end of life. Many districts reported the life span of most of their ITS devices to be around 7 to 10 years. Several districts reported that while the design life of housings of most of their DMSs was 20 years, the electronic components have a design life around 7 to 10 years. Several districts reported the life span of most cameras to be between 5 and 6 years.

The majority of the districts reported that they do not have any formal processes or criteria to help in making equipment procurement, deployment, and replacement decisions. In addition, these districts do not have formal processes or procedures in place to track performance measures or factors such as mean time between failures, mean time to repair, average repair costs, design life, or salvage values.

LIFE-CYCLE DECISION SUPPORT TOOLS

Districts do not appear to be using a single statewide asset management/decision support system to track maintenance histories of devices and assist in repair/replacement decision-making. Most districts have developed their own processes (i.e., spreadsheets) and systems for tracking maintenance histories, but they are not generally linked to their TMC management software. Generally, these methods have been developed locally to support specific needs of individual districts.

One district reported using a commercially available tool that is integrated with the traffic management software system that is used to track maintenance and software issues. The tool allows the operators to submit maintenance repair requests and to track the status of repairs through the system.

The Division does maintain an inventory of ITS devices for the entire state. This inventory is updated annually. Each district is required to provide the Division with a yearly report detailing the inventory of their devices. The list includes the locations of deployed field devices, and information about the type and manufacturer of each device. The Division is responsible for maintaining this inventory and sending the list of devices to the districts for verification. Many districts are uncertain in regard to how this information is used by the Division.

CHAPTER 4. FACTORS AFFECTING INSTALLATION AND MAINTENANCE DECISIONS RELATED TO ITS DEVICES

The TTI research team convened a panel of ITS experts within TxDOT to discuss the key factors that affect their decisions to install, replace, or retire ITS devices and systems. This expert panel was composed of representatives from several districts that operate ITS system as well as representatives from Traffic Operations Division (TOD). The research team led the expert panel through a facilitated discussion of the following topics:

- Reasons or specific situations for installing video surveillance system, detection systems, and dynamic message signs.
- Critical factors affecting their decisions to deploy these ITS systems in the field.
- Important factors considered for the maintenance, replacement, or removal of ITS devices.
- Situations and conditions when removing ITS field devices might be appropriate.
- Existing processes, tools, and documentation requirements used to justify the installation or removal of ITS devices.
- Strategies and techniques for determining and allocating maintenance budget dollars to necessary installations and repairs to their systems.

The research team also asked the expert panel to rate the level of importance and significance of factors that influence the decision-making process.

The following provides specific situations and factors identified by the research team that could potentially influence the decisions to install, repair, or remove ITS devices by TxDOT. These situations and factors were used by the research team in the development of warrants guidelines and requirements for these devices.

REASONS AND CONSIDERATIONS FOR INSTALLING ITS DEVICES

The following provides specific reasons and factors identified by the research team that influence the decision to install ITS devices in the field.

Dynamic Message Signs

Dynamic message signs, sometimes also referred to as changeable message signs or variable message signs, are the primary means that TxDOT uses to convey important traffic and travel information to motorists while en route to their destination. TxDOT uses these signs to provide travelers with up-to-the-moment information about travel and traffic conditions likely to be encountered downstream of the sign location. These signs provide travelers with real-time information that advises them of problems and conditions ahead, and in some cases, provides them with a suggested course of action. Typical types of information conveyed on these signs for traffic management purposes include the following:

- Early warning messages. These messages give motorists advance notice of slow traffic and queuing ahead. These messages are intended to alert travelers to the potential of a stopped traffic condition ahead.
- Advisory messages: These messages provide motorists information about specific problems along their route ahead. These messages are intended to encourage motorists to change their speed or path, as the situation dictates, in advance of the problem area.
- Alternate route messages: These messages are intended to influence motorists to travel to their destination using a different route than originally intended.

Typical traffic management applications where DMSs are used to perform the following functions:

- Provide road or ramp closures and diversion information during emergency situations, such as incidents and crashes.
- Provide information related to the source and location of expected congestion as part of a comprehensive congestion management effort.
- Encourage diversion to alternate routes upstream of bottleneck locations.
- Provide end of queue warning or queue present information upstream of bottleneck locations.
- Provide information about adverse weather or environmental conditions that could potentially impact travel.
- Provide information about current and future construction or maintenance operations.
- Provide AMBER Alert messages and other similar types of messages, such as Silver, Blue, and Endangered Missing Persons Alerts.[1]
- Provide routing and parking information associated with special events and special event venues such as car shows or sports events.
- Provide route status and reception information for intercity and interstate travelers during hurricane evacuations and other emergency.
- Provide roadway status and travel time information to key destinations ahead in the corridor.
- Provide special public safety message and public service announcements.
- Encourage diversion to alternate routes by special classes of vehicles such as commercial trucks.
- Provide route signing and status information about special traffic generators (e.g., parking and delay information for cruise ship terminal).
- Provide roadway and travel status information at edge of district boundaries.
- Provide information about use restrictions and tolling rates for managed lane applications.

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[1] Silver Alerts are messages associated with the Silver Alert Network (2007) intended to assist law enforcement personnel in the recovery of missing senior citizens with documented mental impairments. Blue Alerts are messages associated with the "Blue Alert" program which was enacted by Governor Perry in 2009 to assist in the speedy apprehension of violent criminals who kill or seriously wound local, state, or federal law enforcement officers in the line of duty. Endangered Missing Persons Alerts (2011) are messages intended to assist law enforcement in the recovery of missing persons with an intellectual disability.

The *Texas Manual on Uniform Traffic Control Devices* prohibits the use of DMSs for outdoor advertising purposes (*15*).

TxDOT generally uses two types of DMS: permanent and portable. Permanent DMSs are signs that are mounted on permanent structures installed in the ground or on other highway superstructure. These signs are generally larger in their display capabilities and are well suited for traffic management purposes. Portable DMSs are those that are truck or trailer-mounted so they can be moved to locations where they are needed. They are generally used when the need to provide information is temporary or related to specific, short-lived events. Therefore, these types of signs are generally used for construction and maintenance activities as well as special events.

Based on information contained in the literature as well as conversation with operations personnel, TxDOT generally installs DMSs for traffic management purposes at the following locations:

- Upstream of known bottlenecks and high crash locations.
- Upstream of major diversion decision points, such as interchanges.
- In and around permanent major special event venues and trip generators.
- Upstream of sections of highways where sudden changes in weather or travel conditions may occur.
- Upstream of access points to toll and/or managed lanes.
- Along emergency and/or hurricane evacuation routes to provide way finding and reception area information.
- As part of a comprehensive traffic management system for a region or area.

Other factors that might influence the selection of locations to install new permanent DMS devices include the following:

- Identified in the area's Regional ITS Architecture.
- The proximity of other DMS to the location (e.g., spacing 3 to 5 miles in urban areas).
- The potential to use the device to provide different types of traffic management information (i.e., weather alerts, incidents, evacuation routes, etc.).
- The availability and connectivity to power and communications.
- Site distance and visibility to the sign.
- The classification of the roadway (freeway versus highway versus arterial route).
- The exposure to traffic (i.e., high volume, major commuting route).
- The overall traffic management capabilities of the region.
- Whether the site is located in an urban, suburban, or rural location.
- The ability and resources needed to operate and maintain the device.
- The proximity of other ITS equipment to support operations (i.e., CCTV cameras).
- The availability and suitability of right of way.
- The amount of competing visual "clutter" associated with the proposed site.
- The ability to provide protection for sign supports.
- Near state or district boundaries (one in each direction within 5 miles from boundary).

Video Surveillance/CCTV

TxDOT has a long history of using video surveillance/CCTV cameras for providing visual surveillance on their freeway systems. Video surveillance systems are used by TxDOT operators to monitor freeway traffic flow, and provide improved incident management capabilities.

Most of TxDOT's video surveillance systems deploy pan/tilt/zoom functions on the cameras. This allows the operator to reposition the camera to be able to view multiple directions of freeway from a single camera installation. Most TxDOT video surveillance deployments transmit full motion video, which generally requires a higher bandwidth center-to-field communications environment.

TxDOT does use compressed video and/or snapshot videos to provide visual images from remote locations and/or at locations where low bandwidth communications exists.

Typical reasons for installing a CCTV camera station include the following:

- To provide real-time monitoring of traffic conditions along major commuting corridors to assist in real-time decision-making by freeway operators for deployment of traffic management strategies.
- To provide monitoring capabilities of a known bottleneck location to detect the formation (and dissipation) of congestion.
- To provide detection and visual confirmation of the location, severity, and extent of traffic incident.
- To provide real-time monitoring of traffic conditions along major hurricane evacuation routes.
- To provide real-time monitoring of traffic conditions associated with special events around major permanent event venues.
- To provide detection and/or verification of deteriorating weather and/or road surface conditions due to weather.
- To provide visual information to travelers about traffic and travel conditions via website and/or the media.
- To provide real-time monitoring, congestion/incident detection, and response verification around major construction.
- To provide visual confirmation that other ITS field devices are functioning as intended (i.e., verify messages on dynamic message signs, gates are down at flood-prone crossings, etc.).
- To provide monitoring of traffic operations at remote traffic signals and other important traffic management junctions.
- To provide real-time monitoring capabilities at major facility interchanges (i.e., freeway-to-freeway interchanges or managed lanes access points).
- To provide security surveillance support of critical infrastructure such as bridges, tunnels, ferry landing, border safety inspection facility (BSIF), etc.

Other factors that may affect the location of a CCTV camera include the following:

- The physical geometrics of the roadway (both vertical and horizontal).
- The proximity of other CCTV camera stations (generally to be able to see 1 mile in each direction).
- The availability and connectivity to power and communications.
- The ability to access the site by maintenance vehicles (device serviceability).
- The availability of a site that is minimally affected by traffic vibration (e.g., bridges).
- The presence of current (or anticipated) features (such as sign support, bridges, high mask poles, etc.) that might obstruct the view from the camera.
- The ability to locate the camera outside the clear zone or within protection of other devices.
- The ability to observe arterial streets in addition to the freeway.

Traffic Detection Station

Traffic sensor stations consist of a series of technologies that are used to measure traffic conditions and provide data that are used by other systems. These stations provide TxDOT operators with data such as speed, volume, and occupancy from point locations. The stations can also be used to support segment-based information, such as segment travel times.

A number of technologies can be used to provide traffic sensor data including the following:

- Loop detectors.
- Radar-based detectors.
- Acoustic detectors.
- Magnetometers.
- Video image processors.
- Probe-based systems [e.g., Bluetooth, radio frequency identification (RFID) tag readers].

Typical reasons for installing a traffic sensor station include the following:

- To provide real-time monitoring of traffic conditions along major commuting corridors.
- To provide data needed to make control decisions for traffic management devices (such as ramp meters).
- To provide data (such as travel time or travel information) to support traveler information systems.
- To provide data to support active traffic management applications, such as variable speed advisories, variable speed limits, queue detection, dynamic tolling applications, truck rollover systems, etc.
- To provide wrong-way vehicle detection along limited access facilities, including freeway mainlanes and HOV lanes.
- To provide queuing and wait time information at border crossings to support border protection.
- To provide weight and height information in support of commercial fleet operations.
- To support long-range and operational performance monitoring and planning activities.

- To support toll revenue collections systems on toll facilities.

For most freeway management applications, traffic sensors are mounted outside traditional travel lanes, generally located on the outside shoulder area. This placement eliminates the need to establish lane closures in order to install, maintain, or remove the sensor technology.

Other factors that influence decisions to install a traffic sensor station include the following:

- The availability and connectivity to power and communications.
- The accessibility of the site to maintenance vehicles.
- The type and data needs of the applications being supported by the sensor.
- The proximity of other sensors.

REPLACEMENT VERSUS REPAIR

The decision to repair versus replace failed equipment is a complex one. In general, TxDOT's general philosophy is to repair a device as long as it can be repaired and the cost for doing so does not exceed the cost of a new device.

Many TxDOT districts have maintenance contracts under which ITS devices are repaired, and in many cases it is up to the maintenance contractor to make recommendations to TxDOT to either repair the device or replace the device.

The following factors were identified as factors affecting decisions about whether to replace or repair malfunctioning equipment:

- The replacement cost of the device.
- The age of the equipment and the amount of life-time remaining.
- The availability of replacement and maintenance funds.
- The repair history associated with the particular device (what has been repaired in the past and what is likely to need repairing in the immediate future).
- The types and magnitudes of repairs needing to be performed.
- The costs and availability of spare or replacement parts.
- The nature of the device and how it affects the overall ability of TxDOT operators to implement traffic management responses.
- The magnitude of the repairs versus the cost of maintaining or repairing the device.
- The availability of new technologies.
- The connectivity and interdependence of other systems on the use of the device.
- Statewide procurement practices and policies.
- Administrative criteria to promote uniformity and standardization of devices.
- The type and level of customer support available from the device vendor.
- The amount of risks associated with repairing the device (i.e., the likelihood that the repair will return the device to functional operation).

REMOVAL OF DEVICES

Agencies must frequently make the key decision whether to remove aging or obsolete devices. At some point, the cost of repairing and maintaining a device that has outlived its usefulness can place a severe financial drain on agencies. In general, the decision to remove an ITS device is based on a number of factors, including the following:

- The device is no longer functional and cannot be repaired within a reasonable cost.
- The device no longer serves or provides the functions for it they was originally installed.
- Traffic or roadway conditions have changed such that the device is not able to provide accurate or timely information about travel conditions.
- The structural elements used to support the devices (support structure, sign bridge, etc.) have reached the end of their design life.
- Major design changes or new roadways constructed in the vicinity or traffic pattern changes make the location undesirable or ineffective.
- Ownership of the facility is transferred to another operating agency.
- The location is no longer considered part of the critical infrastructure.
- Another device can provide similar information of the location or roadway segment of interest.
- The equipment is no longer supported and/or replacement parts are no longer available.
- New, more efficient technology is available that can be used to perform the functions of the device.
- The location has diminished in terms of its “importance” from a traffic management standpoint.

CHAPTER 5. "WARRANT" CRITERIA AND SUNSET REQUIREMENTS FOR ITS DEVICES

In this task, the TTI research team adapted "warrant" criteria for installing and "sunsetting" (i.e., the removal or replacement) specific ITS field devices. Specifically, installation "warrants" and sunset requirements were developed for the following types of ITS devices:

- Dynamic messages signs.
- Video surveillance/closed-circuit television stations.
- Traffic detectors/ traffic sensor system station.

These "warrants" are not intended to be rigid threshold conditions that, if found to be satisfied, mandate the installation or removal of these devices (a "shall" condition); instead, the term "warrant" is used here to imply guidance criteria that would assist TxDOT in justifying the installation, replacement, or retirement of either an individual device or a system of devices. Whenever possible, the warrants provide thresholds and conditions that can be quantified through field measurements. To the extent possible, the warranting criteria:

- Identify the purpose or use of the specific devices.
- Provide the conditions or criteria that might justify the need to install or remove each type of device.
- Provide recommendations under which *partially satisfying* the major conditions might justify the installation or removal of a device.

ENTERPRISE POOLED FUND STUDY

Much of the material used in developing these proposed warrants was based on the research study "Warrants for Installing and Use of Technology Devices for Transportation Operations and Maintenance" funded through an FHWA Pooled Fund Study (ENTERPRISE), of which TxDOT is a contributing member (*16*). The study conducted a series of projects to develop preliminary warrants for nine ITS devices. The warrants were designed to assist agencies with deployment decisions and site selection. ENTERPRISE continues to test and refine the warrants while exploring industry acceptance for the concept. The overall approach to developing the ITS warrants was modeled after the Manual on Uniform Traffic Control Devices warrants for traffic signal installations (*17*). Warrants were developed for the following nine ITS devices:

- Closed-circuit television.
- Road weather information system.
- Dynamic message signs.
- Intelligent work zone deployments.
- Highway advisory radio (HAR).
- Ramp meters.
- Curve warning systems.
- Variable speed limits.
- Dynamic speed display systems.

Table 3 shows CCTV and DMS warrants developed as part of the ENTERPRISE Pooled Fund Study. These warrants provided the basis for the proposed criteria, several of which are based directly on the warrant criteria developed in the ENTERPRISE Pooled Fund Study. Furthermore, the original ENTERPRISE warrants have been revised or augmented with additional criteria for some conditions, and new criteria have been developed for some of the cases.

PROPOSED CRITERIA TO JUSTIFY THE INSTALLATION OF ITS DEVICES

The research team recommends that TxDOT use the following criteria to justify the installation of new ITS devices.

Dynamic Message Signs

Dynamic message signs are an important element of a TxDOT ITS deployment. DMSs represent the primary way that most TxDOT districts provide en-route traffic and travel information to motorists on TxDOT facilities. Common applications where DMSs are used include, but are not limited to, the following:

- Provide warning to drivers about the locations and source of potential or actual hazards downstream.
  - Traffic congestion.
  - Stopped traffic.
  - Incidents.
- Provide traveler information related to diversion/alternate route during:
  - Special events.
  - Hurricane evacuation.
- Provide information related to status of roadway conditions.
  - Travel time/route status.
  - Road weather conditions.

TxDOT also uses DMSs to display safety messages, transportation-related messages, emergency- and homeland-security related messages, and AMBER Alert messages.

Table 3. ENTERPRISE Pooled Fund Warrants for Dynamic Message Signs and Closed-Circuit Television Field Deployments.

Warrant	Purpose
DMS Systems	
DMS Warrant – 1: To Inform Traveler of Weather Conditions	To provide road weather information to drivers so that the drivers can choose whether to continue travel on the route or whether to adjust their speed, route of travel, or divert from the trip in anticipation of an upcoming weather hazard.
DMS Warrant – 2: To Inform Traveler of Traffic Conditions	To provide current traffic status information (incidents, congestion, travel time, road work) to drivers so that drivers can choose to divert to avoid the situation, to reduce driver anxiety, and to reduce crashes involving drivers encountering unexpected stopped traffic.
DMS Warrant – 3: Changing Traffic Control or Conditions	To notify drivers in advance of special changing traffic conditions and roadway configuration changes associated with road construction or maintenance in order to reduce driver confusion that could result in a crash.
DMS Warrant – 4: Special Events	To provide parking or alternate route information about special events or major venues to drivers in order to reduce congestion and delays due to unnecessary "circling the block" or non-participating drivers being caught in traffic.
DMS Warrant – 5: Parking Availability	To provide real-time parking availability information to drivers to avoid unnecessary "circling the block" looking for parking spots.
DMS Warrant – 6: Transit Park-and-Ride Lot Availability	To provide real-time parking availability information to drivers regarding transit park-and-ride lots.
DMS Warrant – 7: Evacuation Routes	To provide evacuation route information to drivers during disaster or homeland security events.
DMS Warrant – 8: Jurisdictional Information	To provide jurisdictional specific information to drivers at or near borders between two jurisdictions.
CCTV Systems	
CCTV Warrant – 1: Traffic Observation for Signal Control Change	To visually observe traffic conditions in order to determine if alternate signal timings are appropriate before implementing alternate traffic signal timing plans remotely.
CCTV Warrant – 2: Traffic Incident or Event Verification	To allow traffic operations personnel or emergency response teams to visually verify traffic flow and/or incidents (e.g., crashes, debris in roadway) in order to activate or dispatch appropriate response and post messages to traveler information systems.
CCTV Warrant – 3: Weather Verification	To allow maintenance dispatchers and traffic control personnel to verify weather conditions on the roadway, either to guide traveler information dissemination or to dispatch snow removal and treatment operations.
CCTV Warrant – 4: Traveler Information	To allow travelers to understand traffic delay and road weather conditions by viewing images of the roadway from the Internet prior to departing.
CCTV Warrant – 5: Field Device Verification	To allow traffic or maintenance operations personnel to verify operational functionality of in-field devices (such as dynamic message signs, road/lane closure gates, and other devices).
CCTV Warrant – 6: Intelligent Work Zone	To allow travelers or transportation professions to understand construction or maintenance traffic delay by viewing images of the roadway remotely.

Source: *Warrants for the Installation and Use of Technology Devices for Transportation Operations and Maintenance (16)*

The typical components associated with the installation of a DMS include the following:

- Message display unit (or sign).
- Mounting structure.
- Controller cabinet housing the message display and communication control equipment.
- Communication system connecting DMS to control center.

The following represents criteria that could be applied for determining when and where installation of a CCTV camera station might be appropriate to support traffic management, traveler information, and infrastructure protection purposes. The satisfaction of one or more of these criteria does not necessarily in itself require the installation of a CCTV station but implies where installation of a CCTV station may be beneficial to TxDOT. Additional factors should be considered in determining the physical location and design of each CCTV station.

DMS Criterion #1: Provide En-route Traffic Condition and Congestion Warning Information

Purpose: To provide current traffic status information (incidents, congestion, travel time, road work) to drivers so that drivers can choose to divert to avoid the situation, to reduce driver anxiety, and to reduce crashes involving drivers encountering unexpected stopped traffic.

Conditions: A DMS field station may be justified at a proposed location for purposes of providing en-route traffic condition and congestion warning information if the following conditions are satisfied:

- Condition #1: There is a reliable, real-time source for status information for the target area, ***and***
- Condition #2: The area encounters events that unexpectedly stop traffic an average of at least two times per month***, and***
- Condition #3: One or more of the following is true:
  - Acceptable alternate routes with adequate capacity exist to accept vehicles that may divert based upon the information, ***or***
  - The location is a stretch of road where traffic diversion is not possible and travelers would benefit from information describing the cause and/or extent of delays in order to relieve driver anxiety or confusion, ***or***
  - Horizontal or vertical curvatures create safety issues when traffic is stopped unexpectedly, ***and***
- Condition #4: The location experiences one or more of the following:
  - There are at least 2 hours of delay during peak travel periods where traffic flows exceed 1100 vehicles per hour per lane, ***or***
  - The facility is operating at Level of Service C or worse during the majority of the day, ***or***
  - The facility experiences a minimum AADT volume threshold of:
    - For 2-lane facilities: 16,800 vehicles per day.
    - For 4-lane facilities: 33,600 vehicles per day.
    - For 6-lane facilities: 50,400 vehicles per day.
    - For 8-lane or more facilities: 67,200 vehicles per day.

DMS Criterion #2: Provide Information Related to Special Events or Special Event Sites

Purpose: To provide parking or alternate route information about special events or major venues to drivers in order to reduce congestion and delays due to unnecessary circulation of event traffic and/or adverse impacts on non-event traffic.

Conditions: A DMS field station may be justified at a proposed location for purposes of providing information related to special events and traffic circulation to, from, and around special event venues if the following conditions are satisfied:

- <u>Condition #1</u>: Event venue is located in close proximity to a major travel way, ***and***
- <u>Condition #2</u>: Venue routinely hosts ticketed events with definable peaking characteristics (i.e., rapid and tight arrival and/or departure patterns for specified start and end times), ***and***
- <u>Condition #3</u>: The following conditions routinely create traffic congestion:
    - There are at least two weekday ticketed events per week during season, ***or***
    - Venue typically hosts more than four events per year attracting 30,000 visitors or more in one day, ***or***
    - Venue typically attracts 1,000,000 or more visitors per year, ***and***
- <u>Condition #4</u>: A need exists to disseminate alternate parking and traffic options to direct visitors to one or more preferred options.

DMS Criterion #3: Provide Information Related to Evacuation Routes and Reception Areas

Purpose: To provide drivers with information related to evacuation route and evacuation destinations/shelters during disasters or homeland security events.

Conditions: A DMS field station may be justified at a proposed location for purposes of providing emergency evacuation information if the following conditions are satisfied:

- <u>Condition #1</u>: Location is on a route designated an official TxDOT Major Hurricane Evacuation Route or Potential Contraflow Route (*18*),. ***and***
- <u>Condition #2</u>:
    - Location is upstream of major reception areas for evacuees, ***or***
    - Major decision points/interchanges along evacuation routes.

DMS Criterion #4: Provide Information Related to Road Weather Travel Conditions

Purpose: To provide road weather information to drivers so that the drivers can choose to continue travel on the route or whether to adjust their speed, route of travel, or divert from the trip in anticipation of an upcoming weather hazard.

Conditions: A DMS field station may be justified at a proposed location for purposes of providing road weather information if the following conditions are satisfied:

- <u>Condition #1</u>: Location is prone to weather-related hazards that drivers would not otherwise be forewarned about, ***and***

- Condition #2: Weather events contribute to a significant number of crashes or road closures such that there are major impacts to drivers (this may include one or more annual closures or crashes on a freeway/interstate highway or 10 or more annual crashes or closures on rural roadways), ***and***
- Condition #3: Reliable road weather information is available for the area downstream of the candidate DMS location, ***and***
- Condition #4: The capability exists (either manually by staff members or automated through a condition reporting system, such as a linkage to a road weather information station) to create event-specific descriptions of weather conditions to be displayed on the DMS, ***and***
- Condition #5: At least one of the following is true:
  - A recurring need exists to disseminate event-specific descriptions (rather than a lower technology approach such as activating a flashing warning sign that says "Weather Alert When Flashing"), ***or***
  - Options exist for either alternate routes or services that might be described on the DMS where drivers may safely wait out extreme conditions, ***or***
  - Lower technology mitigations (such as flashing beacon signs) have been tried and not proven to be effective.

If Condition #1 ***or*** #2 above is satisfied, the device may be justified. If one or more additional purposes are partially satisfied at this location for this device, the device may be considered.

DMS Criterion #5: Provide Information Related to Managed Lanes Operations

Purpose: To provide specific information to drivers related to the pricing, occupancy, or other requirements at or near access points to managed lanes facilities.

Conditions: A DMS field station may be justified at a proposed location for purposes of providing information related to the operations of managed lanes facilities if the following conditions are satisfied:

- Condition #1: Location is upstream of entry points to managed lane facilities, ***and***
- Condition #2: Use of managed lanes is dynamic (that is, pricing and/or occupancy change can vary throughout day), ***and***
- Condition #3: Lower technology has been tried and not proven to be effective, ***and***
- Condition #4: The need exists to convey other information related to the operations of the managed lanes.

Other Considerations

The *Texas Manual on Uniform Traffic Control Devices* (*15*) indicates that the following factors should be considered when installing a permanent DMS:

- DMS should be located sufficiently upstream of known bottlenecks and high crash locations to enable road users to select an alternate route or take other appropriate action in response to a recurring condition.

- DMS should be located sufficiently upstream of major diversion decision points, such as interchanges, to provide adequate distance over which road users can change lanes to reach one destination or the other.
- DMS should not be located within an interchange except for toll plazas or managed lanes.
- DMS should not be positioned at locations where the information load on drivers is already high because of guide signs and other types of information.
- DMS should not be located in areas where drivers frequently perform lane-changing maneuvers in response to static guide sign information, or because of merging or weaving conditions.

Video Surveillance/Closed-Circuit Television Stations

TxDOT has used closed-circuit television systems as their primary means of monitoring traffic performance on the freeway systems for many years. TxDOT typically uses CCTV cameras for the following purposes:

- Monitoring traffic flow conditions to support implementation of traffic management responses.
- Providing visual detection and verification of traffic incidents or capacity disruption events.
- Providing information to travelers for pre-trip planning purposes.
- Verifying message displays on changeable message signs.
- Monitoring environmental conditions (e.g., visibility distance, wet pavement).
- Observation of traffic signal operations at interchanges.
- Protection and security of critical infrastructure elements.

For fixed location CCTV stations, video cameras are permanently mounted either on existing structures along the freeway or on specially installed camera poles. The typical components associated with the installation of a video surveillance/CCTV station include the following:

- Video camera unit.
- Mounting structure (existing or newly installed).
- Controller cabinet housing the camera monitoring and control equipment.
- Communication system connecting the camera to the control center.
- Video monitors and camera controls located in the control center.

The following represents criteria that could be applied for determining when and where installation of a CCTV camera station might be appropriate to support traffic management, traveler information, and infrastructure protection purposes. The satisfaction of one or more of these criteria do not necessarily in itself require the installation of a CCTV station, but implies where installation of a CCTV station may be beneficial to TxDOT. Additional factors should be considered in determining the physical location and design of a CCTV station.

CCTV Criterion #1: Support the Implementation of Traffic Management Responses

Purpose: To monitor traffic flow conditions on streets and highways for the purposes of determining when and where to deploy and/or alter traffic management responses.

Conditions: A CCTV field station may be justified at a proposed location for purposes of supporting the implementation of traffic management responses if the following conditions are satisfied:

- Condition #1: The candidate location is part of, or an extension of, a comprehensive traffic management system designed to implement active traffic management responses, ***and***
- Condition #2: Deployment of established traffic management strategies requires visual conformation by an operator before responses can be implemented, ***or***
- Condition #3: Implementation of a traffic management response requires real-time monitoring and decision-making by operators, ***and***
- Condition #4: The location experiences one or more of the following:
  - At least 2 hours of delay occurs during peak travel periods where traffic flows exceed 1100 vehicles per hour per lane, ***or***
  - The facility is operating at Level of Service C or worse during a majority of the day, ***or***
  - The facility experiences a minimum AADT volume threshold of:
    - For 2-lane facilities: 16,800 vehicles per day.
    - For 4-lane facilities: 33,600 vehicles per day.
    - For 6-lane facilities: 50,400 vehicles per day.
    - For 8-lane or more facilities: 67,200 vehicles per day.

Generally, CCTV/video surveillance stations deployed for these purposes are part of an overall traffic management system.

CCTV Criterion #2: Traffic Incident or Event Detection/Verification

Purpose: To allow traffic operations personnel or emergency response teams to visually verify traffic flow and/or incidents (e.g., crashes, debris in roadway) in order to activate appropriate response, dispatch personnel, and/or post messages to traveler information systems.

Conditions: A CCTV system may be justified at a proposed location for the purposes of supporting traffic incident or event detection and verifying if the following conditions are satisfied:

- Condition #1: The section of roadway to be visible from the CCTV station experiences incidents as frequently as twice per month for arterial streets or once per month for freeways, ***and***
- Condition #2: The incident or event has the following effects on the roadway:
  - For freeways, the incident or event causes at least 15 minutes of delay to travelers while the incident is active and has not been cleared, ***or***
  - For arterials, the incident or event causes traffic progression between intersections to be interrupted resulting in cycle failures (vehicle queues not clearing during green intervals of the signal phase) for a duration of at least 15 minutes, ***and***
- Condition #3: The location experiences one or more of the following:
  - At least 2 hours of delay during peak travel periods where traffic flows exceed 1100 vehicles per hour per lane, ***or***

- The facility is operating at Level of Service C or worse during the majority of the day, ***or***
- The facility experiences a minimum AADT volume threshold of:
  - For 2-lane facilities: 16,800 vehicles per day.
  - For 4-lane facilities: 33,600 vehicles per day.
  - For 6-lane facilities: 50,400 vehicles per day.
  - For 8-lane or more facilities: 67,200 vehicles per day.

CCTV Criterion #3: Support Traveler Information Needs

Purpose: To allow travelers to understand traffic delay and road weather conditions by viewing images of the roadway prior to departing.

Conditions: A CCTV system may be justified at a proposed location for the purposes of supporting traffic information needs if the following conditions are satisfied:

- <u>Condition #1</u>:
  - The location (or locations visible from the camera) is prone to disruptions of service that travelers would not be otherwise forewarned, ***or***
  - The location is part of or an extension of a comprehensive system to provide travelers real-time information about the status and conditions, ***or***
  - The location is in a remote area that receives considerable traffic volume due to commercial vehicle traffic or recreational traffic, ***and***
- <u>Condition #2:</u> Either or both of the following are true:
  - The roadway is considered to be a major commuting corridor, a critical alternate route, and/or route of regional significance in the community, ***and/or***
  - The location is considered a critical junction or element of a traveler's route, departure time, and/or mode choice decision-making process.

If any item under Condition #1 above is satisfied, the justification may be considered 'Partially Satisfied.' If one or more other criterion is partially satisfied at this location for this device, the device may be considered.

CCTV Criterion #4: Verification of Road Weather Conditions

Purpose: To allow maintenance dispatchers and traffic control personnel to verify weather conditions on the roadway, either to guide traveler information dissemination or to activate emergency treatment operation or dispatch maintenance personnel.

Conditions: A CCTV system may be justified at a proposed location for the purposes of providing verification of road weather conditions if the following conditions are satisfied:

- <u>Condition #1</u>: The location typically encounters at least 10 significant weather events each season, ***and***
- <u>Condition #2</u>: Weather events have a significant impact and/or represent a specific hazard to travelers at or downstream of the location, and it is a location that travelers are frequently concerned about, ***and***

- Condition #3: If one or more of the following exists:
    - No nearby weather sensors reporting real-time conditions, ***or***
    - No regular manual observations and reports of visibility, precipitation, or pavement temperatures, ***or***
    - Nearby weather sensors would be enhanced through the capability of visual observation, ***or***
    - Site is remotely located where significant travel times may exist for manual confirmation.

If Conditions #1 and #3 are satisfied, the justification may be considered 'Partially Satisfied.' If one or more other criterion is partially satisfied at this location for this device, the device may be considered.

CCTV Criterion #5: Verification of Field Device Operations

Purpose: To allow traffic or maintenance operations personnel to verify operational functionality of in-field devices (such as dynamic message signs, road/lane closure gates, and other devices).

Conditions: A CCTV system may be justified at a proposed location for the purposes of providing verification of field device operations if the following conditions are satisfied:

- Condition #1: The proper operations of the field device can be remotely monitored by a camera, ***and***
- Condition #2: If either of the following is true:
    - The failure of the device presents a safety hazard, ***or***
    - The ability of the operator to implement traffic management responses would be significantly degraded without visual confirmation, ***or***
    - The camera operation would avoid unnecessary trips to verify functionality of the field device.

If Conditions #1 and #2 above are satisfied, the device may be justified. If one or more additional purposes are partially satisfied at this location for this device, the device may be considered.

CCTV Criterion #6: Observation of Traffic Signal Operations

Purpose: To visually observe traffic conditions in order to determine if alternate signal timings are appropriate before implementing alternate traffic signal timing plans remotely.

Conditions: A CCTV system may be justified at a proposed location for the purposes of observing traffic signal operations if the following conditions are satisfied:

- Condition #1: There are typically periods of time at least twice per week of 'loaded' cycles (i.e., where the vehicles in the queue do not all dissipate in one green cycle) that last 15 minutes or longer, ***and***
- Condition #2: The signalized intersection has sufficient cross street traffic such that visual observation is needed to determine if alternate signal timings are appropriate to

benefit the primary direction of flow (i.e., in order to verify that the secondary street is not backing up) , ***and***
- Condition #3: The operations personnel have the ability to activate special event timing plans remotely.

If either Condition #1 or #3 above is satisfied, the device may be justified. If criteria for one or more additional purposes are partially satisfied at this location for this device the device may be justified.

CCTV Criterion #7: Protection and Security of Critical Infrastructure Elements

Purpose: To allow traffic operations personnel or emergency response teams the ability to monitor critical infrastructure elements to facilitate security and protection.

Conditions: A CCTV system may be justified at a proposed location for the purposes of providing protection and security of critical infrastructure elements if the following conditions are satisfied:

- Condition #1: The location is considered to be a critical element of the transportation infrastructure, ***and***
- Condition #2: If the loss of infrastructure elements results in the following:
  - Significant loss and damage consequences (e.g., theft, loss of life, environmental impacts, replacement costs and downtime), ***or***
  - Significant consequences to public services (e.g., emergency response functions, government continuity, important military operations), ***or***
  - Significant consequences to the general public (e.g., available alternatives, community dependency, economic impact, function importance, symbolic importance).

Other Considerations

Other important factors to consider when determining where to install CCTV camera stations include the following:

- The camera should be strategically located to obtain a complete view of the subject roadway segment.
- Camera location should provide the ability to view any nearby DMS for message verification.
- A camera's location should provide the ability to view crossing features (i.e., streets, rail, bridges, etc.).
- Camera structures must be placed in accordance with TxDOT requirements for rigid objects within the right of way.
- Device placement should be such that it accommodates access for service and maintenance with minimal to no impact on traffic. For instance, the use of lowering devices to allow cameras to be lowered from the pole top to ground level for servicing with little or no disruption of traffic.

- The requirements, location, and accessibility of power sources for all the system components must be met.
- Any communication requirements, including availability of communications infrastructure needed to integrate the traffic sensor system (TSS) with the central software, must be met.

Traffic Sensor System Stations

Traffic sensor system stations are standalone point detectors that detect the presence of vehicles and their characteristics. They can detect and provide valuable real-time and historical data, including speed, volumes, vehicle presence, occupancy, gaps, and incident occurrence. TxDOT uses the data provided by these sensors to perform a variety of functions, including:

- Real-time traffic and incident management.
- Traveler information.
- Performance monitoring and measurement.
- Regional and statewide planning and design.

The following represents criteria that could be applied for determining when and where installation of a TSS station might be appropriate to support traffic management, traveler information, and infrastructure protection purposes. The satisfaction of one or more of these criteria does not necessarily in itself require the installation of a TSS station but implies where installation of a TSS station may be beneficial to TxDOT. Additional factors should be considered to determine the physical location and design of the TSS station.

TSS Criterion #1: Support the Implementation of Traffic Management Responses

Purpose: To allow traffic operations personnel to assess the operational status of a facility and deploy, monitor, and adjust traffic management responses in measured traffic conditions.

Conditions: A TSS station may be justified at a proposed location if the following conditions are satisfied:

- Condition #1:
    - The data from the candidate location are to be used by operators and other systems to assess the real-time status of traffic conditions, ***or***
    - The data from the candidate location are to be used by an automated algorithm or decision support system to control a traffic management device (i.e., traffic signal, ramp meter, variable speed advisories, etc.), ***and***
- Condition #2: The location is situated on a route of regional significance, ***and***
- Condition #3: Similar data cannot be provided by another traffic sensor station in close proximity to the proposed location, ***and***
- Condition #4: Data provided by the traffic sensor can be supported by TxDOT LoneStar Intelligent Transportation System software;

TSS Criterion #2: Support the Traveler Information System

Purpose: To allow collection of information to support the dissemination of link travel times through en-route and pre-trip traveler information systems (such as website, 5-1-1, or private information providers).

Conditions: A TSS station may be justified at a proposed location if the following conditions are satisfied:

- Condition #1: The data from the candidate location are to be used by operators and decision support system to provide real-time operational status and road weather conditions information for pre-trip and en-route traveler information systems, ***and***
- Condition #2: The location is situated on a route of regional significance.

TSS Criterion #3: Support Performance Monitoring and/or Long-Range Planning

Purpose: To allow traffic operations personnel to assess the operational status of a facility and deploy, monitor, and adjust traffic management responses in measured traffic conditions.

Conditions: A TSS station may be justified at a proposed location if the following conditions are satisfied:

- Condition #1:
  - The data from candidate location are to be used by operators and the decision support system for the generation of traffic performance measures for assessing the effectiveness and responsiveness of traffic management strategies, ***or***
  - The data from the candidate location are needed to support long-range regional and statewide planning functions, ***and***
- Condition #2: The location is situated on a route of regional significance, ***and***
- Condition #3: Another traffic sensor station in close proximity to the proposed location cannot provide similar data.

Other Considerations

In addition to the criteria provided above, the designer must also consider the purpose and system needs for the data; the type of technology used with the TSS; and the structural requirements and orientation of the sensors. Other factors to be considered in determining whether a TSS station is appropriate include the following:

- The deployment must be consistent with the needs outlined in a Concept of Operations or Regional Operations Plan and with the approved Regional ITS Architecture.
- The deployment must satisfy the precision considerations established in the system needs.
- The detector deployment must satisfy the spacing considerations established for meeting system needs. Generally, TSS should not be located closer than ½ mile to one another, unless necessary to perform a traffic management function.
- The accessibility requirements (i.e., access to a roadside cabinet) needed to perform maintenance and support on the system components must be met.

- The requirements, location, and accessibility of power sources for all the system components must be met.
- Any communication requirements, including availability of communications infrastructure needed to integrate the TSS with the central software, must be met.

PROPOSED SUNSET REQUIREMENTS FOR THE REMOVAL OF ITS DEVICES

A key decision that agencies frequently have to make is whether to remove aging or obsolete devices. At some point, the cost of repairing and maintaining a device that has outlived its usefulness can place a severe financial drain on agencies. TxDOT should routinely examine its use of ITS devices and consider removing those devices that are: 1) no longer functional, and 2) not serving or providing the functions for which they were originally installed. The following subsections provide criteria and conditions where removal of an ITS device might be justified.

Sunset Requirements for DMS Installations

Conditions where removal of a DMS installation may be justified include:

- Locations where the information load on drivers is high because of guide signs and other types of information.
- Locations not sufficiently upstream of known bottlenecks and high-crash locations to enable road users to make appropriate decisions in a timely and safe manner (i.e., selecting an alternate route or slowing down in response to recurring downstream condition.
- Adequate distance does not exist over which road users can change lanes to reach a decision-point.
- There is the potential for disseminating the primary message through other means (i.e., hybrid sign).
- The installation has reached end of life of structural elements of the DMS (support structure, sign bridge, etc.).
- Major design changes have occurred at the location.
- There is a major new roadway constructed in the vicinity, or traffic pattern changes make the location undesirable or ineffective.
- Ownership of the facility is transferred to another operating agency.
- DMS use is less frequent than anticipated. Support data needed would include the following:
  - Number of times sign was used for primary purpose (times per year).
  - Frequency of different types of message displayed over last three years.

Sunset Requirements for CCTV Installations

The following represent conditions where removal of a CCTV installation may be justified:

- Changes to roadway geometrics limits what can be viewed by the existing location.
- The communication infrastructure no longer supports the existing CCTV location.
- The location is no longer considered part of the critical infrastructure.

- Another location exists that provides better visual coverage of the location or roadway segment of interest.
- The equipment is no longer supported and/or replacement parts are no longer available.

Sunset Requirements for TSS Installations

The following are conditions where removal of a TSS installation may be justified:

- Changes to roadway geometrics limit the quality of data.
- Alternative strategies/technologies exist for getting similar information.
- Traffic management functions are no longer supported or needed at the location.
- Another location exists that provides better coverage and quality of data.
- Replacement equipment is no longer supported or available.
- The location has diminished in terms of its “importance” from a traffic management standpoint.

CHAPTER 6. ASSESSMENT OF CURRENTLY AVAILABLE ASSET MANAGEMENT/RISK MANAGEMENT TOOLS AND DECISIONS SUPPORT SYSTEMS

Asset management is a set of business principles and best practice methods for improving resource allocation and utilization decisions (*19*). Furthermore, it is a systematic process for effectively operating, maintaining, upgrading, and expanding physical assets throughout their life cycles (*20*). Asset management involves (*19*):

- Making resource allocation decisions based on well-defined policy goals and objectives, which reflect desired system condition, level of service, and safety provided to customers, and are often linked to other key goals related to the economy and environment.
- Day-to-day and strategic management supported by performance measures directly linked to the policy goals.
- Analysis of options and alternate methods for achieving desired objectives to decide how to allocate funds within and across different types of investments (e.g., preventive maintenance versus rehabilitation, pavements versus bridges, capacity expansion versus operations).
- Use of quality data and tools capable of providing needed data in an effective manner and to assist with performance tracking and predictions.
- Monitoring to provide feedback on impacts and performance.

Three types of investment categories exist, and decisions about them are interdependent and often require tradeoff analysis (*19*). These are described below:

- **Preservation** – Actions to extend the life of assets and to repair damages that impede mobility and safety. Preservation is achieved through capital projects and maintenance activities.
- **Operations** – Real-time service and operational efficiency provided by the transportation system for both people and freight movement on a day-to-day basis. Examples of operations actions include intelligent transportation systems, which involve real-time traffic surveillance, monitoring, control, and response; and traffic signal control at intersections and entrance ramps. Significant infrastructure (i.e., traffic management centers, communications infrastructure, etc.) is needed to provide operations capability, requiring capital and operating budget and staff resources.
- **Capacity Expansion** – Actions needed to expand the existing system's ability to provide service for both people and freight. Capacity expansion can be achieved either by adding physical capacity to an existing asset, or acquiring/constructing a new facility. However, operational improvements to mitigate congestion may be an appropriate, and in many cases the only feasible, alternative.

Asset management can be applied at project, program, and agency levels. In general, it requires the following steps (*21*):

1. Establishment/identifications of mission, goals, and policies.
2. Preparing an inventory of assets, assessment of their value, identification of their functions, and services they provide.
3. Assessing the condition and performance of assets. This step includes both past, present, and predicted future conditions and performance. This step also includes an assessment of how assets can be preserved, maintained, and improved to increase their life/value, while providing acceptable service.
4. Budget allocation based on existing resources, availability of funds, and projected level of future funding. This step requires analysis of alternatives (i.e., cost-benefit analysis, life-cycle costing, risk analysis, etc.) and optimizing the selection of options or subsets of options. Data needed for this analysis may include unit costs, service life and deterioration models, discount rate, value of time, accident costs, speed, delay, etc.
5. Project/program selection and implementation.
6. Performance analysis to evaluate the impacts of decisions on the achievement of goals and objectives and to determine if any policies need to be revised.

Computer-based tools or systems are needed to support the implementation of the above steps. Numerous such tools have been developed and are commonly referred to as:

- Enterprise asset management (EAM) system.
- Transportation asset management (TAM) system.
- Computerized maintenance management system (CMMS).
- Facilities asset management (FAM).
- Computer aided facilities management.

The specific name generally reflects the type of application, rather than the core functionality (such as a database and a system/tool to manage it), which is very similar across all different asset management tools. For decades, departments of transportation have used asset management systems for managing their primary assets (bridges and pavements). Examples of these tools include:

- Pontis used by TxDOT and 44 other states for bridge management (*22*).
- Pavement Management Information System (PMIS) used by TxDOT (*23*).

Application of asset management tools for managing intelligent transportation systems assets, however, is fairly new. ITS assets are different from other transportation assets in features and characteristics due to the inclusion of electronic devices and communications systems (*24*). In this respect, ITS assets can benefit greatly from real-time asset management features similar to those used for managing information technology (IT) assets.

The next section provides an overview of asset management tools used by various states. Descriptions of selected tools are provided in a following section, and include tools used for managing IT assets.

STATUS OF ASSET MANAGEMENT IN PEER STATES

This section provides an overview of asset management tools being utilized by state DOTs, only a few of which involve ITS assets.

Florida DOT

Florida DOT District 6 (Miami-Dade) ITS office uses a web-based ITS maintenance software application that automates daily device checks to reduce ticket response and repair times of ITS infrastructure, which includes 300 roadway detectors, 200 CCTV cameras, and 70 DMSs (*25*). The application automatically alerts operators when failures occur and prompts them to open a trouble ticket to alert maintenance staff. It also tracks time taken to identify, alert, and respond to each ticket. The module also assists managers to track the performance of the maintenance contractor to ensure compliance. The software calculates penalties associated with non-compliance.

Georgia

The Georgia Department of Transportation uses two tools for managing ITS assets.[2] One of these is the Maximo EAM tool developed by IBM (*26*). Maximo supports the following features used by GDOT:

- An interface for reporting equipment malfunctions.
- Trouble ticketing/dispatching.
- Follow-up of maintenance activities (i.e., what was done to fix a problem).
- Tracking of performance metrics such as mean time before failure over time.

This tool is not intelligent in that it does not have a capability to poll devices to automatically detect device failures. For instance, if a DMS fails, Maximo cannot automatically detect this failure. To overcome this limitation, GDOT uses a second tool named Nagios (*27*), which is a smarter system. Developed for IT systems, it monitors field devices as well and communications infrastructure by polling the devices through their IP address. When Nagios discovers a fault, it generates a maintenance ticket in Maximo. Nagios' graphical interface visually displays the status of devices (green dot for each working device and a red dot for each failed device).

Colorado

The Colorado Department of Transportation uses several tools for managing different assets, and is in the process of developing the cross asset optimization element of its asset management program (*28*). The resulting system will be a system-level rather than a project-level tool. The new system will bring the analysis conducted in other systems into one platform to examine the impacts of dollars invested and the performance of the investment. CDOT uses the following tools/systems for monitoring five categories of assets:

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[2] Interview with GDOT Staff, 2/13/13.

- Deighton Total Infrastructure Management System (dTIMS) CT, launched in 1998, for managing pavements (*29*).
- Pontis, implemented in 1999, for managing bridges (*22*).
- SAP Enterprise Resource Planning (SAP ERP), implemented in 2006, for Level of Service (rather than condition or life-cycle analysis), fleet/equipment, and ITS (*30*). A buildings module of SAP ERP was expected to be launched in January 2013. Migration to SAP ERP in 2006 reduced the number of 120 legacy systems to 50.

Colorado DOT selected Deighton dTIMS CT as its single platform for managing multiple assets. Cost to implement the dTIMS tool to analyze the impact of funding for five statewide programs was estimated at $225,000 with 2000 hours of staff time devoted to the project.

New Jersey

The New Jersey Department of Transporation (NJDOT) monitors nine asset investment categories, which include bridge, pavement, safety, mobility, multimodal, support facilities, mass transit, capital program delivery, and aviation (*28*). For each asset category, NJDOT developed inventory and condition information. NJDOT uses different systems for conducting asset management analysis for different asset categories, allowing project-level optimization within each asset category with specific metrics appropriate to the asset. The tools used for bridges and pavements are Pontis (*22*) and Deighton dTIMS (*29*), respectively.

North Carolina

North Carolina DOT (NCDOT) currently uses asset management tools for maintenance management and pavements (*28*). A bridge asset management system has also been implemented, but is not available at the division level. NCDOT selected AgileAssets' asset management software for three asset categories and plans to use AgileAssets' cross-asset optimization tool (*31*). Prior to 2003, the agency used in-house systems that served primarily as planning tools.

Ohio

Ohio DOT is implementing pavement asset management in an open architecture system that allows for incorporation of other assets (*28*). Optimization is now limited to the pavement system at the system level and not at the individual asset level. Ohio DOT uses Deighton dTIMS for its pavement management system (*29*). The system uses Markov performance prediction analysis to generate forecasts and develop work plans with a goal of achieving a steady-state system condition. A prototype system is in development that will allow for cross-asset optimization at the system level for the agency's three major asset categories: pavement, bridge, and culvert. The prototype will be incorporated into the agency's Web-GIS.

Utah

Utah DOT uses Deighton dTIMS software to manage investments in pavements, bridges and safety, and plans to add other asset categories to this tool over time (*29*). Deighton dTIMS software is used as the agency's pavement management system. Pontis is used to capture bridge inventory data (*22*). The Safety Management System is an in-house database application used by Utah DOT for the entry, storage, retrieval, and analysis of crashes in the state.

Delaware

Delaware DOT (DelDOT) uses IBM's Maximo EAM software for managing road, highways, and related assets. Delaware Transit Corporation (DTC), which is an operating division of DelDOT, decided to leverage this installation and use Maximo EAM software for management and maintenance of DTC assets (*32*). These assets include bus stops, shelters, parking garages, lots, train stations, park-and-ride facilities, maintenance facilities, and office buildings. As part of this implementation Maximo CMMS was customized and configured to accommodate work management structures and processes.

STATUS OF ASSET MANAGEMENT AT TXDOT

TxDOT is in the process of implementing the COMPASS project, a new maintenance management system (MMS) to replace its mainframe-based maintenance management information system (MMIS) (*33*). MMIS provided data for planning and was designed to collect data on selected routine maintenance functions that accounted for the majority of maintenance expenditures, assemble data from other systems to generate reports relating maintenance costs to specific roadway segments, and maintain a county-wise inventory of every state-maintained highway in Texas. To achieve its objectives, MMIS interacted with several computer systems, which included: Construction and Maintenance Contracting System (CMCS), Financial Information and Management System, Material and Supply Management System, Salary Labor and Distribution System, Equipment Operating System (EOS), and Single Entry System.

The MMS being implemented consists of 16 systems and 24 interfaces. These systems and features include: Budget Information System, Customer Relations and Feedback Tracking, Design and Construction Information System (DCIS), the new Fleet Management System, and Pavement Management Information System, Pontis, Texas Reference Marker, Project Costing System, Accounts Payable and Stock Balances, and SiteManager (which replaced CMCS). This implementation provides a comprehensive asset maintenance management that is expected to cover the entire life cycle of asset maintenance contracts, including planning, programming (bidding and awarding), budgeting and payment, work scheduling, monitoring, and inspection, and support for decision-making at different levels. Kuhn et al. provide additional details of the MMS system (*33*).

COMMERCIAL ASSET MANAGEMENT TOOLS

This section provides information about selected commercially available asset management tools, some of which are already being used by state DOTs. The source of this information is vendor web pages and vendor documents available on the Internet in electronic form.

Tools for Traditional Assets

Maximo

Maximo is an enterprise asset management tool developed by IBM for transportation and other applications (*26*). As mentioned in the previous sections, it is used by GDOT for managing ITS assets and DelDOT for other non-ITS transportation assets. In 2012, the City of Austin awarded a contract for purchase and installation of Maximo for work order and maintenance management of public works street and bridge operations (*34*). Maximo provides for:

- Management of planned and unplanned activities, including dispatching and scheduling.
- Tracking and managing (performance monitoring of) assets and location data throughout the life cycle.
- Inventory management that includes knowledge of asset details such as usage, how many, and how valuable.
- Complete support for purchase, lease, warranty, labor rate, and different types of contracts.
- Procurement management.

The Maximo applications layer has the following layers (*35*):

- **Data storage** – Oracle, SQL Server, and DB2.
- **Core foundation services** –security, resource pooling, event management, transaction management, workflow, and messaging services.
- **Business** – work management, service management, asset management, inventory, procurement.
- **User interface** – HTML, XML, Mobile, Web services.
- **Service oriented architecture** – SAP and Oracle.
- **Report server** – HTML, PDF, and Excel.

Maximo supports both GIS-based and linear referencing of assets. Linear referencing scheme is used for spatial assets such as pavements and has been adapted by many DOTs (*36*).

dTIMS

Deighton Total Infrastructure Management System is a decision support system for making decisions about the life cycle of assets such as roads, bridges, water, and safety (*29*). dTIMS provides:

- Inventory management, including locations, current conditions, and future conditions.
- Linear referencing system.
- Browser-based user interface mapping.
- Life-cycle cost analysis capability.
- Strategic cross-asset optimization and trade-off analysis.
- Data security.
- Support for Microsoft SQL Server®, Access®, and Oracle®.

- Performance evaluation, including long-term impacts of work plans and changes in budget allocations.
- Mobile access for key functions.

Additional Deighton software solutions available include:

- dTIMS MM for enterprise-based planning, budgeting, and management of maintenance activities.
- dTIMS wf for automating processes.
- dTIMS md (management dashboard) for accessing key strategic information including maps, graphs, and tabular reports.

AgileAssets

AgileAssets provides a range of software, including a Signal and ITS Manager, for integrated infrastructure asset management (*31*). These solutions are designed to enable complete life-cycle management of infrastructure assets, including pavement, facilities, bridges, fleets, utilities, telecom, traffic signals, signs, and ITS. Features of AgileAssets software include:

- Browser-based UI.
- Asset inventory and data collection.
- Asset condition and history analysis.
- GIS/LRS support to quickly display visual condition, location, and maintenance activity.
- Workflow customization.
- Centralized data entry for assets.
- Support for asset hierarchy.
- Ability to maintain warranty information.
- Work order assignments.

Each core AgileAsset solution (i.e., Signal and ITS Manager) requires the System Foundation base module. Other optional modules include Mobile Inventory Manager and Mobile Work Manager. AgileAssets was selected for TxDOT's COMPASS project described earlier.

SAP

SAP Linear Asset Management tools provide enterprise asset management (EAM) capabilities to manage traditional transportation assets (*30*). Features of SAP EAM include:

- Asset Infrastructure Management.
  - Manage network assets to optimize performance of the total system (while making sure that assets are available for operations).
  - Facilitate and connect day-to-day and big-picture asset management activities.
  - Manage asset safety and performance across the infrastructure life cycle.
  - Evaluate the operational status of assets more accurately.
- Asset Life-Cycle Management.
  - Automate asset life-cycle management with real-time monitoring.
  - Improve compliance and risk management processes for assets.

    - Improve decision support and resource management.
- Operations Management.
    - Control network service quality.
    - Schedule maintenance and dispatching.
    - Manage emergency response and incidents.
    - Schedule investigation and performance reporting.
    - Maintain overall asset network service quality at a high level.
    - Manage emergency responses and incidents with full follow-up.
    - Schedule and confirm investigation and performance reporting.
    - Minimize impact of asset upkeep with scheduled maintenance.

Other Maintenance Management Systems

Dozens of additional commercial maintenance management systems are available for use by public and private agencies. Almost all of them provide functions to support the following business functions:

- Work order.
- Asset management.
- Inventory/Purchasing.
- Preventive maintenance scheduling/management.
- Work scheduling.
- Reports/Dashboard.
- Mobile maintenance/personal digital assistant capability.
- Conditions monitoring for predictive maintenance.

Some of these programs run on vendor servers (*37*), while others run on client servers (*27*). Software that runs on vendor servers are generally priced on a per user monthly fee basis. Per user fee depends on the level of support, training, and other features such as access to API for allowing customization. For instance, eMaint X3 charges range from $40 to $120 per month per user (*38*). Often, such vendors offer pricing packages for multiple users (i.e., 5, 10, or more users/month rate). Also, additional features, such as support for mobile devices, cost extra.

Information Technology Infrastructure Monitoring Tools

ITS assets include roadway sensors, closed-circuit television cameras, dynamic message signs, and other infield assets (infrastructure for device installation, roadside cabinets for housing other related electronic and data processors, power supplies, etc.), communications infrastructure (fiber network system, wireless radio system, cellular modems, hubs, etc.), and equipment in the traffic management center (television monitors, computers, software, video encoders/decoders, switches/routers, etc.). These assets are different from traditional transportation (pavements, bridges, etc.) assets in that they exhibit the following characteristics:

1. Generally require more prompt maintenance.
2. Have shorter useful life.
3. Are prone to obsolescence due to rapid changes in technology.
4. Lend themselves to online/real-time monitoring.

Tools specifically developed and routinely used by agencies for monitoring their IT assets can also be applied to manage these transportation assets. This application can be stand-alone, or used in conjunction with traditional asset management tools. Tools in this category include the following:

Nagios

GDOT uses Nagios for real-time monitoring of ITS devices (*27*). Nagios Core system, which is Open Source, is available free of cost, while additional features and support services are available at various costs. Nagios Core provides the following features:

- Monitors infrastructure components, including applications, services, operating systems, network protocols, and network infrastructure.
- Delivers alerts to staff via email and SMS.
- Handles event to restart failed applications, services, and servers.
- Plans of infrastructure.
- Keeps track of compliance to service level agreements, historical record of historical outages, notification, and responses for later analysis.
- Integrates with other in-house and third-party applications.

Icigna

Icinga is a fork of Nagios (*39*). It is a enterprise grade, open source, and free. It runs on multiple Linux distributions and can monitor any device connected to the network. Its features include:

- Ability to monitor network services (SMTP, POP3, HTTP, NNTP, PING, etc.) and host resources (CPU load, disk usage, etc.),
- Ability to define network host hierarchy using "parent" hosts, allowing detection of and distinction between hosts that are down and those that are unreachable,
- Notifications (via email, pager, etc.) when service or host problems occur and get resolved, and
- Web interfaces for viewing current network status, notification and problem history, log files, and historical information.

Spiceworks

Spiceworks is a free tool for managing all aspects of IT (*40*). Its features include:

- Network management, including monitoring devices, software, services, and users.
- Troubleshooting, alerting, and reporting.
- Network inventory and mapping.
- IT help desk for managing service tickets.
- Ability to manage from Windows server, tablets, smartphones, or remote computer.
- Free online training and tech support.

ServiceDesk Plus

ServiceDesk Plus provides an integrated asset management solution along with the basic help desk functions (*41*). Its asset management provides for an inventory of all the hardware and software assets. In addition, it automatically scans and updates every asset/node with an IP address within the network. Features of this include the following:

- Asset management (life cycle, remote access to workstations).
- Inventory scanning (Windows, Linux, Mac, other network devices, switches, routers, access points, etc.).
- Software metering.
- Configuration management database (track relationships between assets such as connections and usage).
- Purchase order tracking.
- Contract management.

GUIDELINES FOR SELECTING TOOLS FOR MANAGING ITS ASSETS

The driving force to implement asset management for ITS infrastructure likely includes one or more primary goals that are often detailed as implementation reasons, including (*42*):

- Decrease total cost of ownership (TCO).
- Manage technology changes.
- Enhance performance of assets.
- Provide the capability for life-cycle management.
- Minimize security risks.
- Reduce ITS expenditures.
- Maintain or exceed required service levels.
- Reduce over-purchasing.
- Manage maintenance costs.
- Improve the budgeting process.
- Manage outsourcing contract levels.
- Enforce standards.
- Provide best value for redeployment of assets.

Many agencies proceed directly from having goals or desires to the step of tool selection. This process misses several steps that are critical to the success of any asset management solution.

1. **Obtain executive backing** – An asset management system can be an expensive acquisition. Beyond the initial procurement, agencies must consider the on-going support costs, as well as the personnel cost for implementation, data collection requirements, data analysis from the system, and more. Vendors of systems can normally provide typical implementation costs for similar sized agencies and number of assets.
2. **Understand implementation requirements** – Implementing comprehensive asset management requires cooperation between multiple parties, such as operators, managers, procurement, program budgeting, and field personnel. A critical concept to communicate is

overall primary responsibility, as well as those functions within the agency that must provide data to, or perform services from, the asset management system. In other fields, some agencies have set up a stakeholder team prior to any purchase and implementation, to ensure that needs from various viewpoints are identified and fulfilled.

3. **Baseline procedures** – Many agencies have existing baseline procedures they utilize to track assets. These procedures should be identified and evaluated to determine if and how they might change when an asset management system is put in place. An important evaluation point is the human resource requirements associated with these procedures and whether the implementation of a system will require a larger amount of labor. Baseline procedures should also examine the data that result from current procedures and document the expected gains in terms of ability to be more reactive or insightful to infrastructure needs. Also documented are the additional costs, if any, that data analysis will take.
4. **Establish desired metrics** – What are the measurable criteria by which your agency will define success for asset management? How many metrics will you use? Metrics should be established with a target and a timeframe for meeting that target. Metrics can be very specific to an individual agency or asset management implementation, but they serve as critical guidance to keep focus on the initial objectives.
5. **Develop new asset management processes** – While a previous step identified the existing baseline procedures to track assets, the development of new processes to integrate the asset management function into agency tasks is a crucial step toward success. Business processes should identify the key tasks, what departments are responsible for those key tasks, and how the metrics and reporting requirements will be compiled, as well as reported to agency management.
6. **Allocate resources –** Asset management costs money, both in terms of direct dollar expenditures for the software and support and also in the personnel time required to implement and maintain the systems. Many programs have suffered because funds were not programmed to adequately address the needs of the implementation. This step in the planning process might also lead some agencies to consider a wholly or partially outsourced asset management solution.
7. **Select and deploy tool –** The choice of a particular tool or software is the last step in the overall asset management planning process. Tool selection depends on size, needs, budgetary considerations, need for hardware and/or software management, type of metrics analysis and reporting requirements desired, and more. Proceeding through the planning process and identifying goals, objectives, and desired metrics, compared to available budget and personnel can go a long way toward reducing the set of options to a manageable set that can then be judged on purely technical grounds. Overall, asset management tool functions can be broken down into several major categories, including:
    - Asset discovery.
    - Asset repository.
    - Inventory management.
    - Configuration management.
    - Contract management.
    - Financial management.
    - Install/Add/Move/Change management.
    - Incident and problem (helpdesk) management.
    - Report management.

- Procurement management.

In some cases, agencies deploy both an asset management solution and an IT management solution. The difference in the approaches is that IT management is considered real time and activity monitors assets that utilize communication channels. In the world of ITS, this is an ideal solution for devices such as cameras, DMS, TSS sensors, and more.

Typically, IT management solutions address the following major requirements (*43*):

- Device discovery.
- Network mapping.
- Asset provisioning.
- Asset inventory.
- System monitoring.
- System alerting.
- Software distribution.
- Vulnerability assessment.
- Patch monitoring.
- Configuration management.
- Health dashboard.
- Bandwidth monitoring.
- Reporting.

While some functions overlap, the two management solutions serve very different purposes and both have an important role in the enterprise.

NEXT STEPS

TxDOT is currently developing an ITS strategic plan to guide the future deployment and operation of ITS in the state. The draft plan identifies the need to deploy an asset management system for managing and maintaining ITS assets deployed across the state. Once the strategic plan has been finalized and work begins on developing details of steps needed to implement the plan, guidance provided in the previous section can be used in selecting appropriate features of asset management tools appropriate for TxDOT ITS needs. One of the critical decisions necessary at that point would be whether ITS assets are to be managed independent of other assets or integrated with other EAM systems (i.e., those being integrated under the COMPASS project) to facilitate enterprise-level cross-asset optimization. Even if a decision is made to develop an independent asset management system ITS, it would be beneficial to develop a centralized system along with a centralized database.

CHAPTER 7. A RISK-BASED APPROACH FOR MANAGING ITS ASSETS

Understanding risk and how to manage it is emerging as another core competency expected of transportation agencies. The role of a transportation agency is not only to protect the public from hazards and threats to desired transportation outcomes but also to ensure that it identifies, evaluates, and capitalizes upon all reasonable opportunities. To be effective at managing risks, transportation agencies need to develop tools and techniques for identifying and protecting against excessive risk while capitalizing upon opportunities that have acceptable risk levels (*44*).

The use of risk management among US transportation agencies generally is limited to managing risk during construction. However, the Moving Ahead for Progress in the 21st Century (or MAP-21) Act requires agencies to "develop a risk-based asset management plan for the National Highway System to improve or preserve asset conditions and system performance" (*45*).

RISK MANAGEMENT AND ASSET MANAGEMENT

As illustrated in Figure 1, FHWA tends to view risk management as part of an overall management strategy for effectively operating the transportation system at its maximum efficiency. Risk management is intended to work with asset management and performance management to help agencies achieve their strategic objectives.

Source: Federal Highway Administration (*44*)

Figure 1. Relationship between Risk Management, Asset Management, and Performance Management.

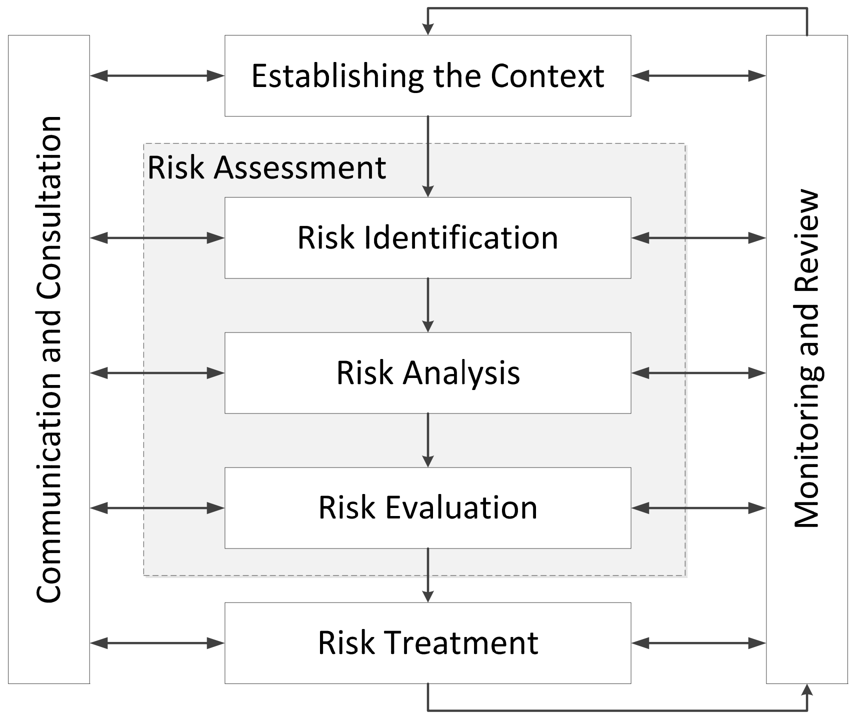
Transportation asset management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their life cycle. Performance management, on the other hand, is defined as an on-going process whereby agencies set strategic policy priorities based upon performance trends and forecasts, which are then used by agencies to guide the development of capital programs and operational activities. Risk management is the process agencies use to identify and mitigate threats and identify opportunities for agency to meet their objectives. All three depend on a similar set of core principles—the use of a systematic process to address strategic issues, relying on sound data and information, and focusing on investments—yet they emphasize different components of the decision-making process. Asset management focuses on the long-term performance of physical assets. Performance management focuses on the effectiveness of policies and investment in achieving desired goals.

RISK MANAGEMENT

The International Standards Organization (ISO) defines risk management as a collection of coordinated activities to direct and control an organization with regard to its risk (*46*). It is a process whereby agencies can identify, analyze, and communicate risk while accepting, avoiding, transferring, or controlling it to an acceptable level considering associated costs and benefits of any actions taken (*47*). Some of the principal benefits of performing an assessment of risks include the following (*48*):

- Understanding the risk and its potential impact upon agency goals and objectives.
- Providing information for decision-makers.
- Contributing to the understanding of risks, in order to assist in selecting treatment options.
- Identifying important contributors to risk and weak links in system and organizations.
- Comparing risks in alternative systems, technologies, or approaches.
- Communicating risks and uncertainties.
- Assisting with establishing priorities.
- Contributing toward incident prevention based on post-incident investigation.
- Selecting different forms of risk treatments.
- Meeting regulatory requirements.
- Providing information that will help evaluate whether the risk should be accepted when compared with pre-defined criteria.
- Assessing risks for end-of-life disposal.

Figure 2 illustrates the basic risk management framework. Each of the steps in the framework is briefly discussed below.



Source: American Society of Safety Engineers (*48*)

Figure 2. Overview of the Risk Management Framework.

Establishing the Context

The first step in a risk management process is for agencies to establish the context in which risks impact the organization, systems, or project being analyzed. Establishing the context defines the basic parameters for managing risk and sets the scope and criteria for the rest of the process. Establishing the context includes considering internal and external parameters relevant to the organization as a whole, as well as the background to the particular risks being assessed. External parameters might include the following:

- Cultural, political, legal, regulatory, financial, economic, and competitive environmental factors.
- Key drivers and trends having impact on the objectives of the organization.
- Perceptions and values of external stakeholders.

Internal factors that an agency should consider in establishing the context of the risk assessment include the following:

- Capabilities of the organization in terms of resources and knowledge.
- Information flows and decision-making processes.
- Internal stakeholders.
- Objectives and the strategies that are in place to achieve them.
- Perceptions, values, and culture.
- Policies and processes.

- Standards and reference models adopted by the organization.
- Structures (e.g., governance, rules, and accountabilities).

Risk Identification

Risk identification is the process of finding, recognizing, and recording the risk to an organization, project, or system. Risk is defined as the effect of uncertainty on objectives (*44*), or more commonly, risk is the chance that something may happen that will have an impact on the performance, ability, or outcome of an agency, system, or project to perform its intended objectives. Objectives can be expressed in many different forms (such as financial, health and safety, and environmental goals) and can apply at multiple levels (such as strategic, organization-wide, project, product, and process).

Risk is often expressed in terms of a combination of consequences of an event occurring and the associated likelihood that the effect will occur. A consequence is defined as the outcome of an event affecting the objective while likelihood is defined as the chance of something (i.e., an event) happening. As risk equates with uncertainty or variability, it can be either positive or negative, depending upon the impact on the objective. An example of a positive risk would be the increase in revenue resulting from a particular investment.

The purpose of this step is to identify what might happen or what situations might exist that might affect the achievement of the objectives of the system or organization. Risk identification involves identifying the causes and sources of risk events, situations, or circumstances that could have a material impact upon objectives and the nature of that impact. Risks can be identified based on historical data, theoretical analyses, informed and expert opinions, and stakeholder's needs. A number of methods can be used to identify risks, including the following:

- Evidence-based methods (such as checklists and reviews of historical data).
- Systematic team approaches where a team of experts follows a systematic process to identify risks by means of a structured set of prompts or questions.
- Inductive reasoning techniques.

Risk Analysis

Once the risks have been identified, the next step in the risk management process is to analyze the risks. Risk analysis consists of determining the consequences and their probabilities for identified risk events, taking into account the presence (or absence) and the effectiveness of any existing controls. The consequences and their probabilities are then combined to determine a level of risk.

Methods used in analyzing risks can be qualitative, semi-quantitative, or quantitative. In a qualitative analysis, consequences, probabilities, and level of risk are defined in terms of qualitative measures (such as high, medium, or low). The resulting combination of consequences and probabilities are also evaluated against qualitative criteria. Semi-quantitative methods use numerical rating scales for consequences and probabilities and combine them to produce a level of risk using a formula. Scales may be linear or have some other relationships. The significance or importance of the different consequences and probabilities also can be recognized by assigning weights to the different factors.

Quantitative analyses estimate values for consequences and their probabilities and quantify the level of risk in specific units defined when developing the context of the assessment. Full quantitative analyses may not always be possible or desirable due to a number of factors, including insufficient information about the system or activity being analyzed, lack of data to support the analysis, or other influences. When this occurs, semi-quantitative or qualitative ranking of risks by knowledge experts familiar with the probabilities and consequences of an event may prove to be an acceptable alternative. Levels of risk should be expressed in terms that are most suitable for the type of risk and analysis form used. Agencies should also recognize that the calculated level of risks is only an estimate, even with a full quantitative analysis. Agencies should take care not to attribute a level of accuracy and precision that is inconsistent with the accuracy of the data and method employed.

Risk Evaluation

The purpose of risk evaluation is to assist in making decisions, based on the outcomes of risk analysis, about which risks need treatment and the priority for treatment implementation. Risk evaluation involves comparing estimated levels of risk with risk criteria defined when the context was established. Based on this comparison, agencies evaluate risks to make the following types of decisions:

- Whether a risk needs treatment.
- Priorities for treatment.
- Whether an activity or a set of activities should be undertaken.
- Whether the course of action taken should continue to be followed and an appropriate path has been selected.

A number of different types of techniques exist that agencies can use to evaluate risks. These techniques are summarized in the appendix. The selection of the appropriate techniques depends on the following:

- The objectives of the study.
- The needs of the decision-makers.
- The type and range of risks being analyzed.
- The potential magnitude of consequences.
- The degree of expertise, human and other resources needed.
- The availability of information and data.
- The need for modification/updating of the risk assessment.
- Any regulatory and contractual requirements.

A risk matrix is a tool that can be used to rank and display risks. The tool provides a means of combining qualitative or semi-quantitative ratings of consequences and probabilities to produce a level of risk or risk rating and can be used to rank risks, sources of risk, or risk treatments on the basis of the level of risk. It is also used by agencies as a common screening for ranking or prioritizing risks, and for identifying which risks need treatment first. It can also be used in situations where insufficient data exist for conducting detailed analyses or in situations that do not warrant the time and effort for more quantitative analyses (*48*). An example of a risk matrix is shown in Figure 3.

Likelihood (36 months)		Likelihood	Risk Map			
≥ 90%	Almost Certain	5	M	H	E	E
≥ 70% to < 90%	Likely	4	M	M	H	E
≥ 25% to < 70%	Possible	3	L	M	M	H
> 1% to < 25%	Unlikely	2	L	L	M	H
≤ 1%	Rare	1	L	L	L	M
Impact		Impact	1	2	3	4
			Minor	Moderate	Major	Extreme

L= Low Risk; M = Moderate Risk; H = High Risk; E= Extreme Risk
Source: Federal Highway Administration (*44*)

Figure 3. Example Risk Matrix.

To construct a risk matrix, risks need to be defined in terms of ranges for both consequences and likelihood. These scales may have any number of points and should cover the range of different types of consequences and probabilities being considered in the analysis (e.g., financial loss, safety, environmental, or other parameters, depending on the context of the assessment). The consequence scale should extend from the maximum credible consequence to the lowest consequence of concern, while the probability scale should correspond from the lowest probability acceptable to the highest defined consequence. Three, four, or five point scales are most common.

Once the ranges of consequences and likelihoods have been defined, risk levels are assigned to each cell in the matrix. The risk levels assigned to the cells depend on the definitions for the probability/consequence scales. The matrix can be established to provide extra weight to either consequences or probabilities, or it may be symmetrical, depending on the needs of the analysis or agency. To rank risks, a user would find the consequence descriptor that best fits the situation, and then define the probability with which those consequences will occur. The level of risk is then read from the matrix. The level of risk can then be linked to decision rules such as the level of management attention or the time scale by which response is needed (*48*).

Risk Treatment

Risk treatment involves selecting one or more options for modifying risks, and implementing those options. Once implemented, treatments provide or modify the controls. Risk treatment involves a cyclical process of:

- Assessing a risk treatment.
- Deciding whether residual risk levels are tolerable.
- If not tolerable, generating a new risk treatment.
- Assessing the effectiveness of that treatment.

Risk treatment options are not necessarily mutually exclusive or appropriate in all circumstances. The options can include the following:

- Avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk.
- Taking or increasing the risk in order to pursue an opportunity.
- Removing the risk source.
- Changing the likelihood.
- Changing the consequences.
- Sharing the risk with another party or parties (including contracts and risk financing).
- Retaining the risk by informed decision.

Selecting the most appropriate risk treatment option involves balancing the costs and efforts of implementation against the benefits derived, with regard to legal, regulatory, and other requirements such as social responsibility and the protection of the natural environment. Decisions should also take into account risks which can warrant risk treatment that is not justifiable on economic grounds, e.g., severe (high negative consequence) but rare (low likelihood) risks.

Monitoring and Review

Both monitoring and review should be a planned part of the risk management process and involve regular checking or surveillance. It can be periodic or ad hoc. The organization's monitoring and review processes should encompass all aspects of the risk management process for the purposes of:

- Ensuring that controls are effective and efficient in both design and operation.
- Obtaining further information to improve risk assessment.
- Analyzing and learning lessons from events (including near-misses), changes, trends, successes, and failures.
- Detecting changes in the external and internal context, including changes to risk criteria and the risk itself, which can require revision of risk treatments and priorities.
- Identifying emerging risks.

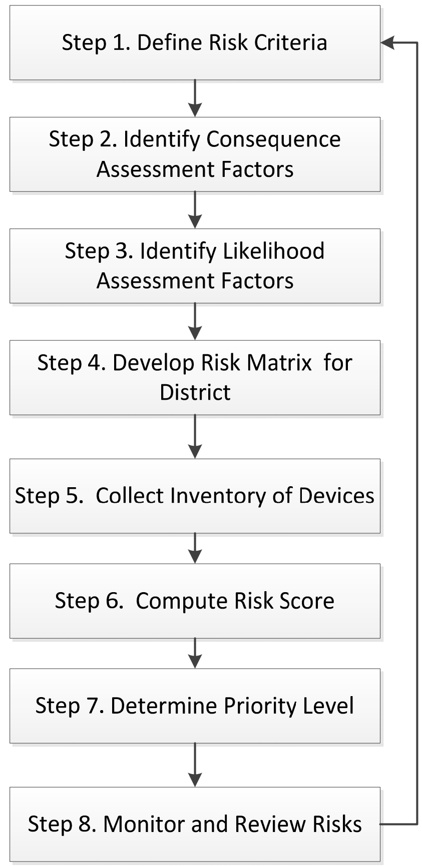
Progress in implementing risk treatment plans provides a performance measure. The results can be incorporated into the organization's overall performance management, measurement, and external and internal reporting activities.

The results of monitoring and review should be recorded and externally and internally reported as appropriate and should also be used as an input to the review of the risk management framework.

RISK-BASED PRIORITIZATION OF ITS ASSETS

Using these risk management principals, the research team applied the risk management principals to develop a framework for conducting a risk-based analysis for prioritizing TxDOT's ITS assets. The framework involves developing a risk matrix to group various ITS assets into priority categories. The intent of the framework is to give TxDOT an easy-to-use tool whereby individual districts can rank their ITS assets based on the criticality of a device to the district's ability to manage traffic operations and the likelihood that the device would fail. The process involves gathering critical information related to the performance, age, and maintenance of the district's ITS assets and assessing the impacts (or consequences) of their failures on overall traffic management capabilities in a district. A ranking system can then be applied to the devices that combines the likelihood and consequences of failure for the identified ITS assets. These assets can then be prioritized based on risk scores and reduction in risk score per unit costs.

Figure 4 provides a summary of the framework, and each step in the framework is provided below. A simple example of the application of the framework is provided in the next section.



Source: Texas A&M Transportation Institute

Figure 4. Framework for Conducting Risk-Based Prioritization of ITS Devices.

Step 1. Define Risk Criteria

The first step in the process of developing a prioritized ranking of ITS assets is to identify the risk criteria by which the devices will be evaluated. The risk criteria are the terms of reference against which the significance of a risk is evaluated (*48*). The criteria should be based on the operational objectives of the district (i.e., staff opinions about the most important traffic management functions performed using the district's ITS assets).

Defining risk criteria involves deciding the following:

- The nature and types of consequences to be included and how they will be measured.
- The way in which probabilities are to be expressed.
- How a level of risk will be determined.
- The criteria by which it will be decided when a risk needs treatment.
- The criteria for determining when a risk is acceptable and/or tolerable.
- Whether and how the combination of risks will be taken into account.

In defining the risk criteria, districts should also consider the following factors:

- The cultural, social, political, legal, regulatory, financial, technological, economic, natural, and competitive environment, whether international, national, regional, or local.
- Key drivers and trends having impact on district and department-level objectives.
- Relationships with and perceptions and values of external stakeholders.

In identifying risk criteria, districts need to be able to define the primary traffic management functions being performed by the devices. For example, a district may have installed a series of DMSs to provide diversion information during incident conditions. The district may have installed another series of signs primarily to provide routing and parking information to a special event venue. The district would need to determine which function is more important to its overall district traffic management mission.

At this stage, it is important for the districts to determine the level of importance of each risk category. This is critical to assigning weights to each risk factor included in the evaluation.

Step 2. Identify Consequences Associated with Device Failure

The next step in the process is to identify the specific consequences associated with failure for each of the devices being evaluated. For example, if a district is trying to prioritize its dynamic message signs, one consequence of a sign not working is that the district will not be able to provide diversion information during incident conditions. The consequences of a sign located in a corridor that experiences a high number of incidents or has a large number of travelers might be considered to be greater than a similar sign located in a less traveled corridor or one experiencing fewer incidents. Each district will need to be able to define the range of consequences that might exist for the devices being evaluated.

A consequence is defined as an outcome of an event affecting objectives. An event can lead to a range of consequences. These consequences may be certain or uncertain, and may have positive or negative effects on the agency's objectives. Consequences can be expressed either qualitatively or quantitatively (*48*).

The research team identified a number of potential factors that could be used to quantify the magnitude of the consequences associated with the failure of the ITS device. These include the following:

- Importance to TMC mission (subjective).
- Number of incidents or incident rate.
- Percentage of hours the facility operates in congested regime.
- Exposure (traffic volumes or ADT).
- Crash rate (3-year average).
- Interdependency with other devices (subjective).
- Loss of quality of data.
- Media value.

Step 3. Identify Factors Affecting the Likelihood of Device Failure

In risk management terminology, "likelihood" is used to refer to the chance of something happening, whether defined, measured, or determined objectively or subjectively. For most ITS assets, the likelihood of a device failure is highly dependent upon the physical condition, historical failures, and the usage of the device. The research team has identified a number of potential factors that could be used to quantify the magnitude of the likelihood that an ITS device will fail. These include the following:

- Age of equipment.
- Percentage of life cycle remaining.
- Hours of use for traffic management purposes.
- Number of repairs per year.
- Mean time between failures.
- Expected time to next failure.
- Time since last failure.
- Level/type of maintenance performed.
- Time remaining under warranty.

Districts need to assign a weight to each selected factor in terms of importance to the individual district. The weighting factors are used to generate a total likelihood of failure score that is used in the assessment process.

Step 4. Develop Risk Matrix

This step involves assigning categories of risk to a matrix using different scales for consequences and probabilities. The consequence scale (or scales) should cover the range of different types of consequences identified in Step 2. These consequences may include financial loss, safety, environment, or other parameters. It is important that the scale should extend from the maximum credible consequence to the lowest consequence of concern. Suggested levels of consequence might include the following:

- **Catastrophic** – This category is intended to reflect that loss of a device in this category would result in a severe degradation in TxDOT's ability to perform its core traffic management functions. Loss of the devices in this category would definitely lead to the formation of extensive queues, cause significant congestion, create substantial delays, reduce TxDOT's ability to execute critical traffic management functions, prohibit agencies from coordinating responses, and create the potential for an increase in major or life-threatening collisions.
- **Major** – This category is intended to reflect that a loss of a device in this category would create major challenges with TxDOT's ability to perform its core traffic management functions. Loss of the devices in this category would likely lead to the formation of queues, restrict TxDOT's ability to execute critical traffic management functions, cause increases in agency response times, and create the potential for an increase in major or life-threatening collisions.
- **Moderate** – This category is intended to reflect that a loss of a device in this category would have moderate consequences on TxDOT's ability to perform its core traffic

management functions. Loss of the devices in this category would likely lead to the formation of moderate queues, cause delays for TxDOT in executing critical traffic management functions, lead to moderate increases in agency response times, and create the potential for moderate increases in injury and property damage crashes.

- **Minor** – This category is intended to reflect that a loss of a device in this category would have only minor consequences on TxDOT's ability to perform its core traffic management functions. Loss of the devices in this category would likely lead to the formation of minor queues, cause minor delays for TxDOT in executing critical traffic management functions, lead to minor increases in agency response times, and create the potential for minor increases in injury and property damage crashes.
- **Insignificant** – This category is intended to reflect that a loss of a device in this category would be inconsequential to TxDOT's ability to perform its core traffic management functions. Loss of the devices in this category would not lead to the formation of queues (even minor ones), result in no significant or measured delays in executing traffic management functions, have no impact on agency response times, or result in any appreciable change in collision potential.

The likelihood scale may need to be established to reflect the likelihood (or probability) that a device will fail within a specified time of the analysis. Definitions for likelihood need to be selected as unambiguously as possible. The scale needs to span the range relevant to the study at hand.

Three general approaches are commonly employed to develop likelihood estimates:

- Relevant historical data are used to identify events or situations that occurred in the past. These data are then used to extrapolate the likelihood of their occurrence in the future.
- Probability forecasts using predictive techniques such as fault tree analysis. Simulation techniques may be required to generate probability of equipment and structural failures due to aging and other degradation processes.
- Expert opinion can be used in a systematic or structured process.

An example of potential levels of likelihood might include the following:

- **Almost Certain** – This level is intended to reflect that the likelihood of a device experiencing an irreparable failure is imminent within the next two years unless immediate corrective action is taken. This category also might reflect devices older than their predicted end of life.
- **Likely** – This level is intended to reflect that a high likelihood exists that a device will experience irreparable failure within the next two years unless corrective action is taken. This category also might reflect devices that are within 90 percent of their predicted end of life.
- **Possible** – This level is intended to reflect that a fair likelihood exists that a device will experience an irreparable failure within the next two years unless corrective action is taken. This category also might reflect devices that are within 75 to 90 percent of their predicted end of life.
- **Unlikely** – This level is intended to reflect that a low likelihood exists that a device will experience an irreparable failure within the next two years unless corrective action is

taken. This category also might reflect devices that are within 25 to 75 percent of their predicted end of life.

- **Rare** – This level is intended to reflect that an extremely low likelihood exists that a device will experience an irreparable failure within the next two years unless corrective action is taken. This category also might reflect devices that are within 25 percent or less of their predicted end of life.

Districts should refine these levels as appropriate for their specific situations and conditions.

Once the appropriate levels have been determined, a matrix similar to that shown in Figure 5 can be generated. The matrix shows consequences on one axis and likelihood (or probability) on the other. A common approach is to divide risks into three bands:

- An upper band where the level of risk is regarded as intolerable whatever benefits the activity may bring, and risk treatment is essential regardless of cost.
- A middle band (or “gray” area) where costs and benefits are taken into account and opportunities balanced against consequences.
- A lower band where the level of risk is regarded as negligible or so small that no risk treatment measures are needed.

Figure 5 shows five priority levels ranging from most critical assets (Priority Level I) to non-critical assets (Priority Level V). Each district would then assign risk levels to each cell in the matrix based on their individual needs and requirements.

CONSEQUENCES OF FAILURE

LIKELIHOOD OF FAILURE	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain	III	II	I	I	I
Likely	IV	III	II	I	I
Possible	V	IV	III	II	I
Unlikely	V	V	IV	III	II
Rare	V	V	IV	IV	III

Priority Level I: Most Critical Assets to Keep Operating

Priority Level II: Important Assets to Keep Operating

Priority Level III: High-Level Assets to Keep Operating

Priority Level IV: Low-Level Assets to Keep Operating

Priority Level V: Non-Critical Assets to Keep Operating

Figure 5. Example Risk Matrix.

Step 5. Collect Inventory of Devices

After defining the criteria, the next step in the process is to collect data on identified risk likelihood and consequence factors associated with each device. Potential sources of information to support this step include the following:

- Average annual daily traffic of the roadway where the device is located.
- Collision frequency on the section of roadways where the device is located.
- Traffic incident frequencies.
- Operational logs.
- Maintenance records and histories.
- Installation and replacement dates.

The level of information that is needed depends on the degree to which quantitative data are used in the assessments.

Step 6. Compute Risk Score

Once the inventory data have been collected for each device to be included in the analysis, the next step is to compute a risk score associated with each device. Risk scores are based upon the combination of likelihood and consequence scores. These can be calculated using the formula in Equations (1) and (2):

$$Likelihood\ Score = (\alpha_1 * LF_1 + \alpha_2 * LF_2 + \cdots + \alpha_n * LF_n) \quad (1)$$

$$Consequence\ Score = (\beta_1 * CF_1 + \beta_2 * CF_2 + \cdots + \beta_n * CF_n) \quad (2)$$

Where,

LF_n = Factor used to assess the likelihood of a device failure.
CF_n = Factor used to assess the consequences of a device failure.
α_n, β_n = Weighting factors associated with each likelihood or consequence factor.

Step 7. Determine Priority Level of Devices

The priority level of each device can be determined by using the computed risk score. Devices that generally have higher risk scores would be listed in higher priority levels while devices with lower risk scores would be assigned to lower priority levels. Districts can then use the ranked listing of devices to make informed treatment decisions. Districts could use the listing to do the following:

- Establish device prioritization needs.
- Identify critical infrastructure for maintenance.
- Assess the overall health of the ITS infrastructure in the district.
- Communicate a common understanding of the levels of risks to the decision-/policy-makers.

Step 8. Monitor and Review Risks

After completing the risk assessment, districts should continue to monitor and update their prioritized list of devices. Districts can expect the factors used in the analysis to vary over time and could change or invalidate the risk assessment. Factors used to assign risks should receive on-going monitoring and review so that risks can be updated when necessary.

EXAMPLE APPLICATION

The following is an example of how this process might be used by a district to develop a risk-based prioritization of their assets. This example is intended to illustrate the application of the framework and is not intended to represent an actual assessment of any particular district.

In this example, a district has five dynamic message signs of various types deployed throughout a particular region. The ITS operations engineer has determined that a prioritized listing of devices is needed in order to assist in allocating a limited amount of resources to operate and maintain the signs. Based on the district's mission, the ITS operations engineer prioritizes these devices based on their importance to the district's overall traffic management mission.

Based on the district's core traffic management mission, DMSs are used in the district to provide the following types of information, in order of importance:

- Route diversion information during incident conditions.
- Traveler advisory and roadway alert information during inclement weather event.
- AMBER and other alerts.
- Travel time information to specific destinations during congested periods.
- Public service announcements and other safety-related messages.

Furthermore, the ITS engineer also determines that some signs are of greater importance to the district's overall traffic management response than other signs. These values are combined to generate the values associated with the consequences of failure shown in Table 4.

Table 4. Example Scale Values for Consequences of Failure of DMS.

Factor	Scale Values for Consequences of Failure				
	1	2	3	4	5
Primary Usage	Public Service Announcements	Travel Time	AMBER Alerts	Weather Advisories	Incident Diversion
Level of Importance	Non-Essential	Low	Moderate	High	Critical

Similarly, the ITS engineer determines that the most critical factors in predicting the likelihood that a device might fail depends on the age of the device as well as the overall repair/maintenance history associated with each sign. The ITS engineer determines that the scale values shown in Table 5 can be used to assess the likelihood of failure.

Table 5. Example Scale Values for Likelihood of Failure of DMS.

Factor	Scale Values for Likelihood of Failure				
	1	2	3	4	5
Age (years)	0–3	4–6	7–10	11–20	>20
Mean Time Between Failures (years)	$\geq$5	4	3	2	1

Based on the mission and the functions performed by the district, the ITS engineer determines the following priorities for ranking the ITS devices deployed in the district:

- Priority Level I (Red): Mission Critical Asset
- Priority Level II (Orange): Important Asset
- Priority Level III (Yellow): Moderate-Level Asset

- Priority Level IV (Green): Non-Mission Critical Asset

Each of these priority levels are then assigned to a cell in the matrix. Devices that fall within Priority Level I, the red shaded portion of the matrix, would be defined as mission critical and represent essential elements that are most likely to have a significant impact on the district's ability to perform their traffic management mission, while devices that fall within Priority Level IV would represent those that are less critical to the district's overall traffic management mission. Figure 6 below shows the priority levels assigned for each cell of the risk matrix.

		Consequence of Failure (Score)				
		Insignificant (1–2)	**Minor (3–4)**	**Moderate (5–6)**	**Major (7–8)**	**Catastrophic (9–10)**
Likelihood of Failure (Score)	**Imminent (9–10)**	III	II	I	I	I
	Likely (7–8)	IV	III	II	I	I
	Possible (5–6)	IV	IV	III	II	I
	Unlikely (3–4)	IV	IV	IV	III	II
	Rare (1–2)	IV	IV	IV	IV	III

Source: Texas A&M Transportation Institute

Figure 6. Example of Assignment of Risk Levels in Risk Matrix.

Once the priority levels have been assigned to the risk matrix, the next step would be for the ITS engineer to collect data related to the evaluation criteria identified in the previous steps. In this particular example, the data needed to prioritize the device might be available from operational and maintenance logs. Table 6 below summarizes the data collected for each of the DMS included in the evaluation.

Table 6. Sample Data for DMS Prioritization Example.

DMS	Age	Repair History (MTBF)	Primary Usage	Level of Importance
A	10	5	Travel Times	High
B	5	3	Diversion	Moderate
C	25	2	PSA	Low
D	2	5	Weather	Critical
E	7	1	Diversion	Critical

Using the collected data, risk scores are computed for each of the DMS devices as shown in Table 7 below.

Table 7. Example Risk Scores for DMS Devices.

DMS	LIKELIHOOD SCORES			CONSEQUENCE SCORES		
	Age	Repair History	Combined Score	Primary Function	Level of Importance	Combined Score
A	3	1	4	2	4	6
B	2	4	6	5	3	8
C	5	4	9	1	2	3
D	1	1	2	4	5	9
E	3	5	8	5	5	10

Using the computed risk scores, the ITS engineer can then determine the priority level associated with each device (see Figure 7). This step is done by first locating the appropriate column for the computed consequence and then determining the appropriate likelihood level (or row) corresponding to that computed for the device. The cell where the two scores intersect represents the priority level for the device. For example, based on the computed score values, DMS A would fall in the Priority Level IV (Green): Non-Mission Critical Asset based on its computed likelihood and consequence score.

		Consequence of Failure				
		Insignificant (1–2)	**Minor (3–4)**	**Moderate (5–6)**	**Major (7–8)**	**Catastrophic (9–10)**
Likelihood of Failure	**Imminent (9–10)**		**DMS C**			
	Likely (7–8)					**DMS E**
	Possible (5–6)				**DMS B**	
	Unlikely (3–4)			**DMS A**		
	Rare (1–2)					**DMS D**

Figure 7. Placement of Example DMSs in Risk Matrix.

Using this technique, the ITS engineer can use the matrix to generate a risk-based priority listing of each of the assets. For the example provided, the priority levels for each of the DMS based on the defined risk criteria are shown in Table 8 below.

Table 8. Risk-Based Priority Listing for DMS Example

Priority Level	Priority Classification	Devices
I	Mission Critical Assets	DMS E
II	Important Assets	DMS B DMS C
III	Moderate-Level Assets	DMS D
IV	Non-Mission Critical Assets	DMS A

The ITS engineer can then use this prioritization scheme to make critical management decisions. For example, if resources are tight and there are not enough maintenance dollars to maintain all the devices to their fullest potential, the ITS engineer may elect to focus the maintenance resources on ensuring the devices in Priority Levels I and II are fully operational because they represent the most important devices to the agency in terms of its traffic management mission.

CHAPTER 8. SUMMARY AND FINDINGS

Over the past several decades, TxDOT has made a significant investment in deploying and maintaining its ITS infrastructure. Much of that infrastructure has reached the end of its life, and districts are faced with difficult questions about whether to install new technologies, repair or replace existing technologies, or remove and abandon technologies deemed no longer viable to support or no longer valuable to their overall operational mission. Managing ITS devices as an asset will allow TxDOT and other regional stakeholders to become more strategic and fiscally responsible in the use of their limited ITS deployment and maintenance funds.

As part of this research project, the research team examined strategies, criteria, and tools that TxDOT could potentially use to help manage their ITS deployments as an asset. Our efforts included the following:

- Summarizing current practices and strategies used in other states for determining when and where to deploy and when to remove ITS field devices.
- Identifying key factors, criteria, and conditions justifying the installation of specific ITS field devices, such as traffic sensors, closed-circuit television, and permanent dynamic message signs.
- Identifying key factors affecting the maintenance of these devices and removal of these devices.
- Developing criteria and documentation procedures to justify the installation, replacement, and removal of these devices to and from the field.
- Identifying tools and techniques that can assist TxDOT in assessing and justifying the need to install and/or repair or remove ITS field devices on Texas highways.

SUMMARY OF FINDINGS

The following provides a summary of the major findings and recommendations of this research.

- Many states have a formal statewide policy or common practice used by all districts in determining when and where to install, replace, or remove ITS devices such as CCTV systems, vehicle detection systems, or dynamic message signs. TxDOT should consider adopting a formal process whereby individual districts can determine when ITS technologies, specifically CCTVs, vehicle detection stations, and DMSs, should be used based on the goals and objectives of the district.
- Few districts reported having formal processes or criteria for determining when to replace ITS field devices. Most districts decide to replace field devices when one or more of the following occur:
    - When multiple failures of components/parts occur.
    - When repair/replacement parts for devices are no longer available.
    - When devices become obsolete.
    - When opportunities exist to replace/update equipment as part of a roadway construction project.
- There do not appear to be any statewide guidelines on routine maintenance. Each district appears to follow its own schedule for performing routine or preventative maintenance,

with the most visible ITS items receiving the most attention. Often maintenance needs are prioritized based on funding availability and importance of corridor rather than importance of devices.

- Districts do not appear to be using a single statewide asset management/decision support system to track maintenance histories of devices and assist in repair/replacement decision-making. Most districts have developed their own processes (i.e., spreadsheets) and systems for tracking maintenance histories, but they are not generally linked to their TMC management software. Generally, these methods have been developed locally to support specific needs of individual districts.
- A number of commercially available asset management tools and technologies exist that can assist TxDOT in managing their ITS deployments as assets. This project highlights some of these tools and provides some recommended guidelines that TxDOT can follow in selecting appropriate tools for managing ITS assets.
- The risk management principles were applied to develop a framework for conducting a risk-based analysis for prioritizing TxDOT's ITS assets. The framework involves developing a risk matrix to group various ITS assets into priority categories. The intent of the framework is to give TxDOT an easy-to-use tool whereby individual districts can rank their ITS assets based on the criticality of a device to the district's ability to manage traffic operations and the likelihood that the device would fail. The process involves gathering critical information related to the performance, age, and maintenance of the district's ITS assets and assessing the impacts (or consequences) of their failures on overall traffic management capabilities in a district. A ranking system can then be applied to the devices that combines the likelihood and consequences of failure for the identified ITS assets. These assets can then be prioritized based on risk scores and reduction in risk score per unit costs.
- Transportation asset management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their life cycle. Performance management, on the other hand, is defined as an on-going process whereby agencies set strategic policy priorities based upon performance trends and forecasts, which are then used by agencies to guide the development of capital programs and operational activities. Risk management is the process agencies use to identify and mitigate threats and identify opportunities for agency to meet their objectives.
- Using these risk management principals, the research team applied the risk management principals to develop a framework for conducting a risk-based analysis for prioritizing TxDOT's ITS assets. The framework involves developing a risk matrix to group various ITS assets into priority categories. The intent of the framework is to give TxDOT an easy-to-use tool whereby individual districts can rank their ITS assets based on the criticality of a device to the district's ability to manage traffic operations and the likelihood that the device would fail. The process involves gathering critical information related to the performance, age, and maintenance of the district's ITS assets and assessing the impacts (or consequences) of their failures on overall traffic management capabilities in a district. A ranking system can then be applied to the devices that combines the likelihood and consequences of failure for the identified ITS assets. These assets can then be prioritized based on risk scores and reduction in risk score per unit costs.

RECOMMENDATIONS

The following provides a brief summary of the recommendations identified in this research project.

Installing ITS Devices

TxDOT participated in a Pooled Fund Study to develop warrants for installing and using ITS devices. The study conducted a series of projects to develop preliminary warrants for nine ITS devices. The warrants were designed to assist agencies with deployment decisions and site selection. The warrants and guidelines developed in the Pooled Fund Study can be applied to TxDOT. Our research project attempted to fine-tune these warrants to make them more directly applicable to TxDOT needs and conditions.

TxDOT should consider adopting the warrant criteria developed through the pooled fund project and fine-tuned in this research. This should promote the consistent application of ITS devices, specifically CCTV camera, vehicle detection stations, and DMS across the state.

Repair vs. Replacement of ITS Devices

TxDOT should adopt a risk assessment/risk management approach for determining when and where to repair versus replace malfunctioning ITS devices. The risk assessment process is designed to assist in making decisions, based on the outcomes of risk analysis, about which risks need treatment and the priority for treatment implementation. Risk evaluation involves comparing estimated levels of risk with risk criteria defined when the context was established. This research report illustrates how this strategy/approach can be used by TxDOT in making this assessment.

Removal of ITS Devices

TxDOT should routinely examine its use of ITS devices and consider removing those devices that are: 1) no longer functional, and 2) not serving or providing the functions for which they were originally installed. Conditions where removal of a DMS installation may be justified include:

- Locations where the information load on drivers is high because of guide signs and other types of information.
- Locations not sufficiently upstream of known bottlenecks and high crash locations which preclude road users from making appropriate decisions in a timely and safe manner (i.e., selecting an alternate route or slowing down in response to recurring downstream conditions).
- Adequate distance does not exist over which road users can change lanes to reach a decision-point.
- There is potential for disseminating the primary message through other means (i.e., hybrid sign).
- Structural elements of the DMS have reached end of life (e.g., support structure, sign bridge, etc.).
- Major design changes have occurred at the location.

- Construction of a major new roadway in the vicinity or traffic pattern changes make the location undesirable or ineffective.
- Ownership of the facility is transferred to another operating agency.
- DMS use is less frequent than anticipated. Support data needed would include the following:
  - Number of times sign was used for primary purpose (times per year).
  - Frequency of different types of message displayed over last 3 years.

The following represents conditions where removal of a CCTV installation may be justified:

- Changes to roadway geometrics limit what can be viewed from the existing location.
- Communication infrastructure no longer supports the existing CCTV location.
- Location is no longer considered part of the critical infrastructure.
- Another location exists that provides better visual coverage of the location or roadway segment of interest.
- Equipment is no longer supported and/or replacement parts are no longer available.

The following are conditions where removal of a TSS installation may be justified:

- Changes to roadway geometrics limit quality of data.
- Alternative strategies/technologies exist for getting similar information.
- Traffic management functions are no longer supported or needed at the location.
- Another location exists that provides better coverage and quality of data.
- Replacement equipment is no longer supported or available.
- Location has diminished in terms of its “importance” from a traffic management standpoint.

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APPENDIX. APPLICABILITY OF TOOLS USED FOR RISK ASSESSMENT

	Risk Assessment Process				
		Risk Analysis			
Tools and Techniques	**Risk Identification**	**Consequence**	**Probability**	**Level of Risk**	**Risk Evaluation**
Brainstorming	SA[1]	NA[2]	NA	NA	NA
Structured or Semi-Structured Interviews	SA	NA	NA	NA	NA
Delphi	SA	NA	NA	NA	NA
Checklists	SA	NA	NA	NA	NA
Primary Hazard Analysis	SA	NA	NA	NA	NA
Hazard and Operability Studies (HAZOP)	SA	SA	A[3]	A	A
Hazard Analysis and Critical Control Points (HACCP)	SA	SA	NA	NA	SA
Environmental Risk Assessment	SA	SA	SA	SA	SA
Structure <<What If?>> (SWIFT)	SA	SA	SA	SA	SA
Scenario Analysis	SA	SA	A	A	A
Business Impact Analysis	A	SA	A	A	A
Road Cause Analysis	NA	SA	SA	SA	SA
Failure Mode Effect Analysis	SA	SA	SA	SA	SA
Fault Tree Analysis	A	NA	SA	A	A
Event Tree Analysis	A	SA	A	A	NA
Cause and Consequence Analysis	A	SA	SA	A	A
Cause-and-Effect Analysis	SA	SA	NA	NA	NA
Layer Protection Analysis (LOPA)	A	SA	A	A	NA
Decision Tree	NA	SA	SA	A	A
Human Reliability Analysis	SA	SA	SA	SA	A
Bow Tie Analysis	NA	A	SA	SA	A
Reliability Centered Maintenance	SA	SA	SA	SA	SA
Sneak Circuit Analysis	A	NA	NA	NA	NA
Markov Analysis	A	SA	NA	NA	NA
Monte Carlo Simulation	NA	NA	NA	NA	SA
Bayesian Statistics and Bayes Nets	NA	SA	NA	NA	SA
FN Curves	A	SA	SA	A	SA
Risk Indices	A	SA	SA	A	SA
Consequence/Probability (Risk) Matrix	SA	SA	SA	SA	A
Cost/Benefit Analysis	A	SA	A	A	A
Multi-Criteria Decision Analysis (MDA)	A	SA	A	SA	A

[1] Strongly Applicable
[2] Not Applicable
[3] Applicable