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1. **INTRODUCTION**

1.1 **What is ITS?**

Intelligent Transportation Systems or ITS is the application of advanced technology to solve transportation problems. ITS supports the movement of people, goods, and services.

ITS improves transportation safety and mobility and enhances productivity through the use of advanced information and communications technologies.

Intelligent transportaation systems (ITS) encompass a broad range of wireless and wire line communications-based information and electronics technologies. When integrated into the transportation system's infrastructure, and in vehicles themselves, these technologies relieve congestion, improve safety and enhance American productivity.

1.2 **Purpose of Manual**

The purpose of MnDOT ITS Project Management Design Manual is to give individuals familiar with ITS elements the process and information necessary to guide the design of intelligent transportation system (ITS) elements for MnDOT. ITS elements have many similarities to traffic signal and roadway lighting elements, but also have many unique characteristics and considerations.

This manual is intended for agency and consultant personnel engaged in ITS component design project management.

This Manual is a living document and could change frequently. Check the MnDOT website for future updates to the manual. This document will be available at, [www.dot.state.mn.us/guidestar/its_technical_resources.html](http://www.dot.state.mn.us/guidestar/its_technical_resources.html).

1.3 **Scope of Manual**

This manual is structured as follows:

- **Section 1** is this introduction to ITS.
- **Section 2** is a glossary of common terms that are used in ITS.
- **Section 3** is a listing of some typical ITS systems (projects)
- **Section 4** discusses some warrants for ITS elements.
- **Section 5** describes the systems engineering process.
- **Section 6** is a discussion on ITS components.
- **Section 7** details the ITS design considerations.
- **Section 8** includes plan development.
- **Section 9** discusses the standard and special provisions.
- **Section 10** is the sample plan set.
- **Section 11** is Code of Federal Regulations(CFR) 23, Section 940

This MnDOT ITS Design manual is not intended to cover all Intelligent Transportation System (ITS) elements. The focus of this manual is on traffic related topics.
1.4 Manual References

The pages contained within the manual are current at the time of publishing. Please keep in mind that the reference material is periodically updated, so the user is cautioned against using the reference materials included in the manual indefinitely, without checking the original sources for updates.

The following table lists the reference material used for this manual.

**Table 1 – Manual References**

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<tr>
<td>Wisconsin Department of Transportation – Intelligent Transportation Systems (ITS) Design Manual, December 2002</td>
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1.5 Disclaimer

This manual is disseminated under the sponsorship of the Minnesota Department of Transportation (MnDOT), Office of Traffic, Safety and Technology. MnDOT and Albeck + Associates assume no liability for its contents or use thereof.

MnDOT does not endorse products or manufacturers. Trademarks of manufacturers’ names appear herein only because they are considered essential to the object of this manual.

The contents of this manual reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official policy of the Minnesota Department of Transportation.
### 2. DEFINITIONS

The chapter defines some of the common terms used in ITS.

#### Table 2 – Glossary of ITS Terms

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<tr>
<th>Term</th>
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<tr>
<td>Architecture</td>
<td>The organizational structure of a system, identifying its components, their interfaces, and a concept of execution among them.</td>
</tr>
<tr>
<td>ATIS</td>
<td>Advanced Transportation Information System</td>
</tr>
<tr>
<td>ATMS</td>
<td>Advanced Transportation Management System</td>
</tr>
<tr>
<td>Automatic Vehicle Identification (AVI)</td>
<td>A technology system using transponders on vehicles and outside sensors to determine if vehicles on toll lanes are carrying a valid transponder and what the vehicle's classification is (truck vs. passenger car, SOV vs. HOV). This system also processes the appropriate toll transaction based on the information.</td>
</tr>
<tr>
<td>Blank-Out Sign (BOS)</td>
<td>A type of DMS that has the capability to show a blank message or one fixed message.</td>
</tr>
<tr>
<td>Changeable Message Sign</td>
<td>A sign that is capable of displaying one of two or more predefined messages, or a blank message. Personnel in the maintenance and construction field usually use the term CMS regardless of whether new messages can be downloaded or whether only pre-defined messages can be used (i.e., whether the sign is a VMS or CMS). A trailer mounted CMS is called a Portable CMS (PCMS). This manual uses the term DMS whether the sign is a VMS or a CMS or a PCMS.</td>
</tr>
<tr>
<td>Closed Circuit Television (CCTV)</td>
<td>A video monitoring and security system used to provide continuous traffic monitoring by the facility operator along the length of the facility and particularly at points of entry and tolling locations.</td>
</tr>
<tr>
<td>CMS</td>
<td>Changeable Message Sign</td>
</tr>
<tr>
<td>Components</td>
<td>Components are the named &quot;pieces&quot; of design and/or actual entities [sub-systems, hardware units, software units] of the system/sub-system. In system/sub-system architectures, components consist of sub-systems [or other variations], hardware units, software units, and manual operations.</td>
</tr>
<tr>
<td>Design</td>
<td>Those characteristics of a system or components that are selected by the developer in response to the requirements.</td>
</tr>
<tr>
<td>Detector Loops (Loop Detector Amplifiers)</td>
<td>An AVC system component imbedded in the pavement and used to detect and classify the type of vehicles passing over them. The loops are linked to the lane controller and can be used individually to count traffic or to trigger the violation enforcement cameras or in tandem to measure vehicle speeds.</td>
</tr>
<tr>
<td>DMS (Dynamic Message Sign)</td>
<td>Any sign system that can change the message presented to the viewer such as Variable Message Sign (VMS), Changeable Message Sign (CMS) and Blank-Out Sign (BOS).</td>
</tr>
<tr>
<td>DOT</td>
<td>Department of Transportation</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<tr>
<td>Dynamic Pricing</td>
<td>Tolls that vary in real time in response to changing congestion levels, as opposed to variable pricing that follows a fixed schedule.</td>
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<td>Express Lanes</td>
<td>A lane or set of lanes physically separated or barriered from the general-purpose capacity provided within major roadway corridors. Express lane access is managed by limiting the number of entranced and exit points to the facility. Express lanes may be operated as reversible flow facilities or bi-directional facilities.</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
</tr>
<tr>
<td>Firmware</td>
<td>The combination of a hardware device and computer instructions and/or computer data that resides as read-only software on the hardware device.</td>
</tr>
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<td>Gap analysis</td>
<td>A technique to assess how far current [legacy] capabilities are from meeting the identified needs, to be used to prioritize development activities. This is based both on how far the current capabilities are from meeting the needs [because of insufficient functionality, capabilities, performance or capacity] and whether the need is met in some places and not others.</td>
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<tr>
<td>Hardware</td>
<td>Articles made of material, such as aircraft, ships, tools, computers, vehicles, fittings, and their components [mechanical, electrical, electronic, hydraulic, and pneumatic]. Computer software and technical documentation are excluded.</td>
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<td>High-Occupancy Toll Lanes (HOT lanes)</td>
<td>Managed, limited-access, and normally barrier-separated highway lanes that provide free or reduced cost access to HOVs, and also make excess capacity available to other vehicles not meeting occupancy requirements at a market price.</td>
</tr>
<tr>
<td>High-Occupancy Vehicle (HOV)</td>
<td>A passenger vehicle carrying more than a specified minimum number of passengers, such as an automobile carrying more than one or more than two people. HOVs include carpools and vanpools, as well as buses.</td>
</tr>
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<td>HOV lane</td>
<td>An exclusive traffic lane or facility limited to carrying HOVs and certain other qualified vehicles.</td>
</tr>
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<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>Incident Management</td>
<td>Managing forms of non-recurring congestion, such as spills, collisions, immobile vehicles, or any other impediment to smooth, continuous flow of traffic on freeways.</td>
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<td>Intelligent Transportation Systems</td>
<td>A broad range of diverse technologies which, when applied to our current transportation system, can help improve safety, reduce congestion, enhance mobility, minimize environmental impacts, save energy, and promote economic productivity. ITS technologies are varied and include information processing, communications, control, and electronics.</td>
</tr>
<tr>
<td>Interface</td>
<td>The functional and physical characteristics required to exist at a common boundary - in development, a relationship among two or more entities [such as software-software, hardware-hardware, hardware-software, hardware-user, or software-user].</td>
</tr>
<tr>
<td>Term</td>
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<tr>
<td><strong>ITS</strong></td>
<td>Intelligent Transportation System[s]</td>
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<td><strong>Lane Controller</strong></td>
<td>A microprocessor ETC component that coordinates the activities of all equipment in a single lane and generates the transactions assigned to individual customers using that lane.</td>
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<tr>
<td><strong>Lane Management Tools</strong></td>
<td>Access – Limiting or metering vehicle ingress to the lane or spacing access so that demand cannot overwhelm HOT lane capacity. See also Limited Access.</td>
</tr>
<tr>
<td></td>
<td>Eligibility – Limiting lane use to specific types of users, such as HOVs, motorcycles, low emission vehicles, or trucks. For most typical HOT lane settings, eligibility requirements would be used during selected hours or at specific access ramps.</td>
</tr>
<tr>
<td></td>
<td>Pricing – Imposing a user fee on a lane that helps regulate demand by time of day or day of week. The fee increases during periods of highest demand.</td>
</tr>
<tr>
<td><strong>Legacy system</strong></td>
<td>The existing system to which the upgrade or change will be applied. Adamitida.</td>
</tr>
<tr>
<td><strong>Level-of-Service (LOS)</strong></td>
<td>Also known as “Traffic Service,” LOS is a qualitative measure describing operational conditions within a traffic stream. LOS assesses conditions in terms of speed and travel time, freedom to maneuver, traffic interruptions, comfort and convenience, and safety. Six levels of service are defined by letter designations from A to F, with LOS A representing the best operating conditions, and LOS F the worst.</td>
</tr>
<tr>
<td><strong>Market packages</strong></td>
<td>Potential products or sub-systems that address specific services [as used in an ITS architecture].</td>
</tr>
<tr>
<td><strong>Metropolitan Planning Organization (MPO)</strong></td>
<td>Federally mandated regional organizations responsible for comprehensive transportation planning and programming for in urbanized areas. Work products include the Transportation Plan, the Transportation Improvement Program, and the Unified Planning Work Program.</td>
</tr>
<tr>
<td><strong>MOE</strong></td>
<td>Measure of Effectiveness</td>
</tr>
<tr>
<td><strong>National ITS Architecture</strong></td>
<td>A general framework for planning, defining, and integrating ITS. It was developed to support ITS implementations over a 20-year time period in urban, interurban, and rural environments across the country. The National ITS Architecture is available as a resource for any region and is maintained by the USDOT independently of any specific system design or region in the nation.</td>
</tr>
<tr>
<td><strong>NEMA</strong></td>
<td>National Electrical Manufacturers Association</td>
</tr>
<tr>
<td><strong>NTCIP</strong></td>
<td>National Transportation Communications for ITS Protocol</td>
</tr>
<tr>
<td><strong>Quality assurance</strong></td>
<td>A planned and systematic pattern of all actions necessary to provide adequate confidence that management, technical planning, and controls are adequate to establish correct technical requirements for design and manufacturing. And to manage design activity standards, drawings, specifications, or other documents referenced on drawings, lists or technical documents.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Queue Jump</td>
<td>Elevated ramps or at-grade lanes that can be used by motorists stopped in traffic to bypass congestion.</td>
</tr>
<tr>
<td>Regional ITS Architecture</td>
<td>A specific regional framework for ensuring institutional agreement and technical integration for the implementation of ITS projects in a particular region.</td>
</tr>
<tr>
<td>RWIS</td>
<td>Remote Weather Information System / Roadway Weather Information system.</td>
</tr>
<tr>
<td>RTIP</td>
<td>Regional Transportation Improvement Plan</td>
</tr>
<tr>
<td>Specification</td>
<td>A document that describes the essential technical requirements for items, materials or services including the procedures for determining whether or not the requirements have been met.</td>
</tr>
<tr>
<td>Stakeholders</td>
<td>The people for whom the system is being built, as well as anyone who will manage, develop, operate, maintain, use, benefit from, or otherwise be affected by the system.</td>
</tr>
<tr>
<td>STIP</td>
<td>Statewide Transportation Improvement Plan</td>
</tr>
<tr>
<td>System</td>
<td>An integrated composite of people, products, and processes, which provide a capability to satisfy a stated need or objective.</td>
</tr>
<tr>
<td>System elements</td>
<td>A system element is a balanced solution to a functional requirement or a set of functional requirements and must satisfy the performance requirements of the associated item. A system element is part of the system [hardware, software, facilities, personnel, data, material, services, and techniques] that, individually or in combination, satisfies a function [task] the system must perform.</td>
</tr>
<tr>
<td>System specification</td>
<td>A top level set of requirements for a system. A system specification may be a system/sub-system specification, Prime Item Development Specification, or a Critical Item Development Specification.</td>
</tr>
<tr>
<td>Systems engineering</td>
<td>An inter-disciplinary approach and a means to enable the realization of successful systems. Systems engineering requires a broad knowledge, a mindset that keeps the big picture in mind, a facilitator, and a skilled conductor of a team.</td>
</tr>
<tr>
<td>TIP</td>
<td>Transportation Improvement Plan</td>
</tr>
<tr>
<td>TMC</td>
<td>Traffic Management Center</td>
</tr>
<tr>
<td>Transportation Demand Management (TDM)</td>
<td>Actions that improve transportation system efficiency by altering transportation system demand using such strategies and facilities as pricing, ridesharing; park-and-ride facilities, transit friendly development / zoning; and employer-based programs—such as staggered work hours and telecommuting. TDM programs improve the efficiency of existing facilities by changing demand patterns rather than embarking on capital improvements.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Transportation System Management (TSM)</td>
<td>Integrated protocols and computerized ITS systems used to manage roadway and transit facilities. TSM techniques improve system capacity without physical expansion or behavioral changes. Typical TSM measures involve continuous management and operation of traffic systems, and utilize integrated traffic control systems, incident management programs, and traffic control centers.</td>
</tr>
<tr>
<td>Variable Message Signs (VMS)</td>
<td>A type of DMS, which allows a user to create and download the message to be displayed into the temporary memory area of the sign controller. This manual uses the term DMS whether the sign is a VMS or a CMS.</td>
</tr>
<tr>
<td>Video Surveillance</td>
<td>The use of pan-tilt-zoom, steerable moving picture cameras to survey a toll plaza, ETC collection area, or a segment of roadway to monitor for incidents.</td>
</tr>
<tr>
<td>WAN</td>
<td>Wide Area Network</td>
</tr>
</tbody>
</table>


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3. **ITS DEVICES AND SYSTEMS**

This section summarizes some of the typical ITS devices and systems. The summaries include:

- Definition
- Purpose and Usage
- Components Used
- Links to pertinent sections of the book for component and design
- Links to websites for additional information on the system

The systems listed here are not all inclusive.

### 3.1 Closed Circuit Television (CCTV)

#### 3.1.1 Definition

A video monitoring and security system used to provide continuous traffic monitoring by the facility operator along the length of the facility and particularly at points of entry and tolling locations.

![Figure 1 – CCTV Camera](image)

#### 3.1.2 Purpose and Usage

CCTV cameras are one of the primary methods of monitoring traffic conditions and detecting incidents. CCTV cameras allow an operator at the traffic management center (TMC) to monitor traffic on both freeways and surface streets to determine the location of congestion and incidents. If an incident or heavy congestion occurs on a freeway, traffic can be diverted to a parallel surface street, and the timing of the signals on the surface street can be modified to provide more green time in the direction parallel to the freeway.

**Detecting Incidents and Advising Motorists**

One of the primary purposes of CCTV is to assist with incident detection. CCTV cameras can be located on both freeways and surface streets, and cameras are especially useful at an interchange where a camera has a view of both the freeway and the surface streets. If an incident is detected on either a freeway or surface street, CMS may be used to alert drivers and to possibly divert traffic elsewhere.
Advising Motorists of Traffic Problems in the Area

CCTV cameras can be used to find a major traffic problem, and DMS can alert drivers to the problem.

Monitoring Traffic Conditions Resulting from Special Events and Advising Motorists

CCTV cameras and DMS are useful during special events, both planned (such as a concert or a football game), as well as unplanned emergencies (such as a terrorist attack or a storm). Special events create traffic patterns that are quite different from normal. Many drivers going to a special event may not normally drive through the corridor in question, and are not familiar with alternate routes. Roadway and lane configurations may be different; for example, a normally two-way road may be converted to one-way in the peak direction, or a road may be closed for security reasons or to provide access for emergency vehicles.

Assisting with Parking Information

CCTV cameras, as well as other technologies, can monitor a large parking lot to determine which lots or sections are full, and CMS (or other methods of information dissemination) can notify drivers as to which parking lots are full or closed, and to direct drivers to parking lots that have available capacity.

3.1.3 Components Used

Typical components used for a CCTV project include the item listed in Table 3 (along with a reference to the section of this manual discussing the component). Warrants for CCTV are discussed in Section 4.1.

Table 3 – CCTV Components and Design Consideration References

<table>
<thead>
<tr>
<th>Component</th>
<th>Component Discussion</th>
<th>Design Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera System</td>
<td>See Section 6.3.1</td>
<td>See Section 7.2.3</td>
</tr>
<tr>
<td>CCTV Mounting</td>
<td>See Section 6.3.2</td>
<td>See Section 7.2.3</td>
</tr>
<tr>
<td>Management System Control Software</td>
<td>See Section 6.1</td>
<td></td>
</tr>
<tr>
<td>Control Cabinet</td>
<td>See Section 1.1</td>
<td>See Section 7.2.5</td>
</tr>
<tr>
<td>Power</td>
<td>See Section 6.12</td>
<td>See Section 7.2.6</td>
</tr>
<tr>
<td>Communications</td>
<td>See Section 6.13</td>
<td>See Section 7.2.7</td>
</tr>
</tbody>
</table>

3.2 Dynamic Message Signs (DMS)

3.2.1 Definition

Any sign system that can change the message presented to the viewer such as Variable Message Sign (VMS), Changeable Message Sign (CMS) and Blank-Out Sign (BOS).
3.2.2 Purpose and Usage

A dynamic-message sign, often abbreviated DMS, is an electronic traffic sign often used on roadways to give travelers information about special events. Such signs warn of traffic congestion, accidents, incidents, roadwork zones, or speed limits on a specific highway segment. In urban areas, DMS are used within parking guidance and information systems to guide drivers to available car parking spaces. They may also ask vehicles to take alternative routes, limit travel speed, warn of duration and location of the incidents or just inform of the traffic conditions.

A complete message on a panel generally includes a problem statement indicating incident, roadwork, stalled vehicle etc; a location statement indicating where the incident is located; an effect statement indicating lane closure, delay, etc and an action statement giving suggestion what to do traffic conditions ahead. These signs are also used for AMBER Alert messages.

3.2.3 Components Used

Typical components used for a DMS project include the following items (along with a reference to the section of this manual discussing the component) are listed in Table 4. Warrants for DMS are discussed in Section 4.2.

Table 4 – DMS Components and Design Consideration References

<table>
<thead>
<tr>
<th>Component</th>
<th>Component Discussion</th>
<th>Design Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Message Sign</td>
<td>See Section 6.4</td>
<td>See Section 0</td>
</tr>
<tr>
<td>Management System Control Software</td>
<td>See Section 6.1</td>
<td></td>
</tr>
<tr>
<td>Control Cabinet</td>
<td>See Section 1.1</td>
<td>See Section 7.2.5</td>
</tr>
<tr>
<td>Power</td>
<td>See Section 6.12</td>
<td>See Section 7.2.6</td>
</tr>
<tr>
<td>Communications</td>
<td>See Section 6.13</td>
<td>See Section 7.2.7</td>
</tr>
</tbody>
</table>
3.3 Highway Advisory Radio (HAR)

3.3.1 Definition
Highway Advisory Radio (HAR) refers to low power AM or FM radio transmissions where localized information is broadcast and travelers are alerted to the presence of the broadcast using static or dynamic signs. The localized transmissions may cover areas that range from 5 miles to 30 miles depending upon the terrain and technologies used. The radio transmissions may be either at fixed permanent locations or mobile devices that may be temporarily located and moved as needed. MnDOT does not currently operate HAR.

Figure 3 – Highway Advisory Radio (HAR) Sign (Iowa DOT)

3.3.2 Purpose and Usage
HAR provides motorist information similarly to DMS but can provide more detailed information. The information broadcast can include:

- Congestion reports
- Hazardous conditions
- Travel times
- Alternate routes
- Special event information
- Parking locations
- Weather and road conditions, and
- Construction information

HAR systems can be permanent or portable. FCC licensing is required, and each HAR site is limited to a maximum of 10-watts of power. HAR can broadcast either AM or FM radio signals, and the typical message length is up to two minutes.

3.3.3 Components Used
Typical components used for a HAR project include the following items (along with a reference to the section of this manual discussing the component):
Table 5 – HAR Components and Design Consideration References

<table>
<thead>
<tr>
<th>Component</th>
<th>Component Discussion</th>
<th>Design Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAR Field System</td>
<td>See Section 6.8.1</td>
<td>See Section 7.2.7</td>
</tr>
<tr>
<td>Communications</td>
<td>See Section 6.13</td>
<td>See Section 7.2.7</td>
</tr>
</tbody>
</table>

3.4 Road and Weather Information System (RWIS)

3.4.1 Definition

Minnesota’s RWIS is a system that automatically collects, processes, and distributes current and forecasted weather and road surface information.

3.4.2 Purpose and Usage

Minnesota’s RWIS includes in-field detectors, communications to relay data to a central processing center, and display mechanisms to display data and resulting information to maintenance and traveler information providers, as well as the traveling public.

Data gathered from a series of in-pavement sensors, sub-surface probes and meteorological equipment were combined with a weather forecast to predict pavement surface conditions up to 12 hours in advance. Advanced traveler information systems provided drivers and fleet operators with RWIS data including up-to-the-minute warnings about changing conditions. Highway operations managers use RWIS for timely and cost-effective snow plowing and deicing.

3.4.3 Components Used

Typical components used for an RWIS project include the items listed in Table 6 (along with a reference to the section of this manual discussing the component). An RWIS warrant is discussed in Section 4.4.
### 3.5 Variable Speed Limit (VSL)

#### 3.5.1 Definition

VSL is a sign capable of displaying different speed limits to travelers (in which the speed limit is either a recommended or mandatory limit) that are either manually activated or controlled by a combination of detectors and algorithms to select appropriate speeds.

![Variable Speed Limit (VSL) Sign](image)

#### 3.5.2 Purpose and Usage

Variable Speed Limit (VSL) signs are used across the country to lower posted speed limits in certain areas. They allow for operators to adjust the posted speed limit without changing the sign. They are used in conjunction with Intelligent Transportation Systems to lower speed limits for several reasons including congestion, construction, accidents, fog, snow, and ice. VSL signs have been successfully tested by several state departments of transportation.

#### 3.5.3 Components Used

Typical components used for a VSL project include the following items (along with a reference to the section of this manual discussing the component):

<table>
<thead>
<tr>
<th>Component</th>
<th>Component Discussion</th>
<th>Design Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>RWIS</td>
<td>See Section 6.6</td>
<td></td>
</tr>
<tr>
<td>Management System Control Software</td>
<td>See Section 6.1</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>See Section 6.12</td>
<td>See Section 7.2.6</td>
</tr>
<tr>
<td>Communications</td>
<td>See Section 6.13</td>
<td>See Section 7.2.7</td>
</tr>
</tbody>
</table>

---

#### Table 6 – RWIS Components and Design Consideration References
Table 7 – VSL Components and Design Consideration References

<table>
<thead>
<tr>
<th>Component</th>
<th>Component Discussion</th>
<th>Design Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sign(s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Management System Control Software</td>
<td>See Section 6.1</td>
<td></td>
</tr>
<tr>
<td>Control Cabinet</td>
<td>See Section 1.1</td>
<td>See Section 7.2.5</td>
</tr>
<tr>
<td>Power</td>
<td>See Section 6.12</td>
<td>See Section 7.2.6</td>
</tr>
<tr>
<td>Communications</td>
<td>See Section 6.13</td>
<td>See Section 7.2.7</td>
</tr>
</tbody>
</table>

3.6 Dynamic Speed Display Signs (DSDs)

3.6.1 Definition

Dynamic speed display signs (DSDS) is a device that detects and displays a vehicle’s current speed back to the driver.

![Figure 6 – Dynamic Speed Display Sign](image)

3.6.2 Purpose and Usage

DSDs have been shown to have a significant speed-reducing effect in temporary applications such as work zones or neighborhood speed watch programs.

3.6.3 Components Used

Typical components used for a DSDs project are listed in Table 8 (along with a reference to the section of this manual discussing the component):
3.7 Ramp Meter

3.7.1 Definition
Ramp Meters are traffic signals on highway entrance ramps, and they are designed to reduce crashes, reduce congestion and provide more reliable travel times.

Figure 7 – Ramp Meter

3.7.2 Purpose and Usage
Ramp metering is a system element for addressing recurring freeway congestion. They control the rate at which vehicles enter the mainline such that the downstream capacity is not exceeded, thereby allowing the freeway to carry the maximum volume at a uniform speed.

Another benefit of ramp metering is its ability to break up platoons of vehicles that have been released from a nearby-signalized intersection. The mainline, even when operating near capacity, can accommodate merging vehicles one or two at a time. However, when platoons (i.e., groups) of vehicles attempt to force their way into freeway traffic, turbulence and shockwaves are created, causing the mainline flow to breakdown. Reducing the turbulence in merge zones can also lead to a reduction in the sideswipe and rear-end type accidents that are associated with stop-and-go, erratic traffic flow.

3.7.3 Components Used
Typical components used for a Ramp Meter project are shown in Table 9 (along with a reference to the section of this manual discussing the component).
Table 9 – Ramp Meter Components and Design Consideration References

<table>
<thead>
<tr>
<th>Component</th>
<th>Component Discussion</th>
<th>Design Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp Meter Signals and Mounting</td>
<td>See Section 6.5</td>
<td></td>
</tr>
<tr>
<td>Management System Control Software</td>
<td>See Section 6.1</td>
<td></td>
</tr>
<tr>
<td>Control Cabinet</td>
<td>See Section 1.1</td>
<td>See Section 7.2.5</td>
</tr>
<tr>
<td>Power</td>
<td>See Section 6.12</td>
<td>See Section 7.2.6</td>
</tr>
<tr>
<td>Communications</td>
<td>See Section 6.13</td>
<td>See Section 7.2.7</td>
</tr>
</tbody>
</table>

3.8 Curve Warning System

3.8.1 Definition

The Curve Warning System provides a programmable active warning based on the speed of the vehicle as it approaches the curve and provides a warning message to the driver to reduce speed if it is excessive.

Figure 8 – Curve Warning Systems

3.8.2 Purpose and Usage

A dynamic curve warning sign (DCWS) is a low-cost technology that may help drivers select an appropriate speed when approaching a horizontal curve. A DCWS generally consists of a warning sign combined with a speed measuring device (e.g., radar) that activates a variable message (e.g., slow down) when vehicles are traveling above a set threshold. The technologies used to create a DCWS are currently available and the devices have been implemented at various locations.

3.8.3 Components Used

Typical components used for a DCWS project include the following items (along with a reference to the section of this manual discussing the component):
### Table 10 – DMS Components and Design Consideration References

<table>
<thead>
<tr>
<th>Component</th>
<th>Component Discussion</th>
<th>Design Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warning Sign (variable message)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed Measuring Device</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Management System Control Software</td>
<td>See Section 6.1</td>
<td></td>
</tr>
<tr>
<td>Control Cabinet</td>
<td>See Section 1.1</td>
<td>See Section 7.2.5</td>
</tr>
<tr>
<td>Power</td>
<td>See Section 6.12</td>
<td>See Section 7.2.6</td>
</tr>
<tr>
<td>Communications</td>
<td>See Section 6.13</td>
<td>See Section 7.2.7</td>
</tr>
</tbody>
</table>
4. **ITS WARRANTS DISCUSSION**

The warrants presented in this section are from the ENTERPRISE pooled fund project. Details can be found at the following link:

http://www.dot.state.mn.us/guidestar/

The above link directs you to the MnDOT ITS Technical Resource page that includes a link to the current ITS Warrants.

The purpose of this section is to assist in the decision making process of determining if a device is warranted or validate existing device deployments. As part of ENTERPRISE research project, warrants were developed for:

- Closed Circuit Television (See Section 4.1)
- Dynamic Message Signs (See Section 4.2)
- Highway Advisory Radio (See Section 4.3)
- Road Weather Information Systems (See Section 4.4)
- Variable Speed Limit Devices (See Section 4.5)
- Dynamic Speed Display Signs (See Section 4.6)
- Ramp Meters (See Section 4.7)
- Curve Warning Systems (See Section 4.8)
- Intelligent Work Zones (See Section 4.9)

These are not official warrants but can be used as guidance toward the determination of ITS components.

The following pages are a handout from “**Warrants for the Installation and Use of - Technology Devices to Assist Transportation Operations, Traffic Management, and Information Dissemination (Warrants for ITS Devices)**” prepared by Athey Creek Consultants for the ENTERPRISE Pooled Fund Study, dated May 14, 2010. This document can be found by visiting the following website:

http://www.acconsultants.org/itswarrants/
8. **ITS Technology Device Warrant Text**

The following pages contain the ITS technology device warrant questionnaires for CCTV, DMS, HAR, R/WIS, VSL signs, DSDS, Ramp Meters, Curve Warning Systems, and Intelligent Work Zones at the time this Final Report is being published. As noted earlier, the most up to date warrants will continue to be maintained on the project website. The project website is: http://www.acconsultants.org/itswarrants

ITS Device Warrants offer a tool to support local transportation professionals in selecting locations for ITS device deployments. Local design standards and guidelines should be the ultimate determining factor in final selection of the locations.
8.1 CCTV Warrants

CCTV shall mean a video or still picture camera system used to collect images and relay images to a central monitoring location, and project images onto a video monitor, television screen, Internet display, or other monitoring equipment.

Six (6) warrants have been identified to capture the most common uses of Closed Circuit Television (CCTV). 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 for Signal Control Changes
Purpose: 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
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 message to traveler information systems.

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.

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.

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).

CCTV Warrant - 6: Intelligent Work Zone
Purpose: To allow travelers or transportation professionals to understand construction or maintenance traffic delay by viewing images of the roadway remotely.
## CCTV Warrant #1: Traffic Observation for Signal Control Changes

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To visually observe traffic conditions in order to determine if alternate signal timings are appropriate before implementing alternate traffic signal timing plans remotely.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Device is warranted if:</strong></td>
<td></td>
</tr>
</tbody>
</table>

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. The operations personnel have the ability to activate special event timing plans remotely.

*Partial Warrant Criteria:*
If either #1 or #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 #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 message to traveler information systems.

**Device is warranted if:**

1. The candidate location encounters incidents as frequently as twice per month for arterial streets or once per month for freeways.

   AND

2. 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

   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 2 hours per day of peak period travel where traffic flow exceeds 1,100 veh/hr/lane; or
   - Conditions considered Level of Service C; or
   - 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.
## CCTV Warrant #3: Weather Verification

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>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.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Device is warranted if:</strong></td>
<td>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. If there are - 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.</td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To allow travelers to understand traffic delay and road weather conditions by viewing images of the roadway from the Internet prior to departing.</th>
</tr>
</thead>
</table>
| **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 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 is in 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 either #1a, #1b, or #1c 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 #5: Field Device Verification

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>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).</th>
</tr>
</thead>
</table>
| Device is warranted if: | 1. The proper operations of the device can be remotely monitored by a camera.  
AND  
2. The failure of the device presents a safety hazard.  
OR  
3. The camera operation would avoid 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’ |
CCTV Warrant #6: Intelligent Work Zone

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To allow travelers or transportation professionals to understand construction or maintenance traffic delay by viewing images of the roadway remotely.</th>
</tr>
</thead>
</table>
| Device is warranted if: | 1. The alignment or traffic control that is visible by a camera image is expected to change periodically during the construction period.  
OR  
The construction zone encounters periods of queues or delays for at least 30 minutes each day.  
AND  
2. The construction zone is in a location where there is not a convenient alternate route for the majority of traffic to deviate from the typical route. |
8.2 DMS Warrants

DMS are defined as either fixed or portable signs capable of displaying any text message entered by an operator (either locally or through remote access).

Eight (8) warrants have been identified to capture the most common uses of Dynamic Message Signs (DMS). While there are other purposes and uses for DMS, the warrants developed to date have focused on the following eight purposes.

The warrants do not distinguish between types of DMS (portable, overhead, roadside). Rather the intent of the warrants is to contribute to the understanding of the need for some type of DMS. Detailed design would contribute to the selection of the specific DMS type.

DMS Warrant - 1: To Inform Travelers of Weather Conditions
Purpose: 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 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.

DMS Warrant - 3: Changing Traffic Control or 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.

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.

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.

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.

DMS Warrant - 7: Evacuation Routes
Purpose: To provide evacuation route information to drivers during disaster or homeland security events.
DMS Warrant - 8:  Jurisdictional Information

Purpose: To provide jurisdictional specific information to drivers at or near borders between two jurisdictions.
## DMS Warrant #1: To Inform Travelers of Weather Conditions

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>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.</th>
</tr>
</thead>
</table>
| Device is warranted if: | 1. If 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. If there is available road weather information for the area downstream of the candidate DMS location.  

   AND  

   3. If 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  

   (either 4-A, 4-B, 4-C)  

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

   OR  

4C. If flashing beacon signs have been tried and not proven to generate responses from travelers.  

   AND |
5. If weather events contribute to a significant number of crashes or road closures such that there are major impacts to travelers (this may include 1 or more annual closures or crashes on a freeway or 10 or more crashes or closures on arterials).

**Warrant Advice:**
If the only warrant being 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 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 #2: To Inform Travelers of Traffic Conditions

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>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.</th>
</tr>
</thead>
</table>
| Device is warranted if: | 1. If the target area is monitored by CCTV cameras, traffic detectors, or another method of monitoring the conditions, or are travel times for the downstream stretch of road

   AND

2. 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 two times per month

   AND

3a. If there are acceptable alternate routes with adequate capacity to accept vehicles that may deviate based upon the information

   OR

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

   OR

3c. If 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 1,100 veh/hour/lane; or
   - Experiences conditions considered Level of Service C; or
   - Experiences 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 #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’.
<table>
<thead>
<tr>
<th>DMS Warrant #3: Changing Traffic Control or Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Purpose:</strong></td>
</tr>
<tr>
<td>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.</td>
</tr>
<tr>
<td><strong>Device is warranted if:</strong></td>
</tr>
<tr>
<td>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</td>
</tr>
<tr>
<td>AND</td>
</tr>
<tr>
<td>2. If the candidate location is upstream of traffic control or construction/maintenance activities that are expected to change more frequently than once every 60 days</td>
</tr>
<tr>
<td>AND</td>
</tr>
<tr>
<td>3. If the speed limit is greater than 45 MPH</td>
</tr>
<tr>
<td><strong>Notes:</strong></td>
</tr>
<tr>
<td>A. If question #2 is not met (activities do not change frequently), lower cost static signage is recommended.</td>
</tr>
<tr>
<td>B. Portable DMS vs. permanent DMS should be considered based on the expected duration of events impacting the area.</td>
</tr>
</tbody>
</table>

**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. If the location contains a venue that houses ticketed events (typically with rapid and tight arrival patterns for a specified start time)
   
   AND
   
   2a. If the event venue typically houses at least two weekday (M-F) ticketed event per week (including seasonal sporting events that only occur during the season)
   
   OR
   
   2b. If the event venue typically houses at least 10 events per year attracting 30,000 visitors or more.
   
   AND
   
   3. If 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. If 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 either #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

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To provide real time parking availability information to drivers to avoid unnecessary &quot;circling the block&quot; looking for parking spots.</th>
</tr>
</thead>
</table>
| Device is warranted if: | 1. If the area contains ample parking to handle the regular visitors, either during commuter periods or special events

AND

2. If 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. If 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. |
<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To provide real time parking availability information to drivers regarding transit park and ride lots.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device is warranted if:</td>
<td>1. If 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. If alternate park-and-ride lots are available (either upstream or downstream) that do not typically fill to capacity. AND 3. If there is the capability (or willingness) to monitor park-and-ride facilities for available spaces.</td>
</tr>
</tbody>
</table>
### DMS Warrant #7: Evacuation Routes

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To provide evacuation route information to drivers during disaster or homeland security events.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Device is warranted if:</strong></td>
<td></td>
</tr>
<tr>
<td>1. If 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).</td>
<td></td>
</tr>
<tr>
<td>AND</td>
<td></td>
</tr>
<tr>
<td>2. If 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).</td>
<td></td>
</tr>
<tr>
<td><strong>Partial Warrant Criteria:</strong></td>
<td></td>
</tr>
<tr>
<td>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’.</td>
<td></td>
</tr>
<tr>
<td>Purpose:</td>
<td>To provide jurisdictional specific information to drivers at or near borders between two jurisdictions.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>
| Device is warranted if: | 1. If there are differing rules or regulations between adjacent jurisdictions

   AND

2a. If display of differing rules or regulations on static signs would either not attract enough attention

   OR

2b. If 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’.
8.3 HAR Warrants

Highway Advisory Radio (HAR) refers to low power AM or FM radio transmissions where localized information is broadcast and travelers are alerted to the presence of the broadcast using static or dynamic signs. The localized transmissions may cover areas that range from 5 miles to 30 miles depending upon the terrain and technologies used. The radio transmissions may be either at fixed permanent locations or mobile devices that may be temporarily located and moved as needed.

Four (4) warrants have been identified to capture the most common uses of Highway Advisory Radios (HAR). While there are other purposes and uses for HAR, the warrants developed to date have focused on the following four.

HAR Warrant - 1: Weather and Driving Conditions
Purpose: To provide road weather information and/or regulatory restriction information (e.g. chain requirements) to drivers in rural areas to alert them to impending conditions.

HAR Warrant - 2: Venue Parking
Purpose: To provide parking or route guidance information around major venues where unfamiliar travelers can benefit from verbal explanations (e.g. airports, National Parks, tourist attractions).

HAR Warrant - 3: Changing Traffic Conditions
Purpose: To notify drivers in advance of special changing traffic conditions and roadway configurations associated with road construction or maintenance.

HAR Warrant - 4: Special Events
Purpose: To notify travelers about special events (either prior to the event start date or during the event), alerting travelers to the impacts of these events on traffic, and to guide event attendees to the event.
<table>
<thead>
<tr>
<th>HAR Warrant #1: Weather and Driving Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Purpose:</strong></td>
</tr>
<tr>
<td>To provide road weather information and/or regulatory restriction information (e.g. chain requirements) to drivers in rural areas to alert them to impending conditions.</td>
</tr>
<tr>
<td><strong>Device is warranted if:</strong></td>
</tr>
<tr>
<td>1. If the location is upstream and within 4 hours driving proximity to locations that are 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).</td>
</tr>
<tr>
<td>AND</td>
</tr>
<tr>
<td>2. If there is available road weather monitoring devices or manual observations for the area downstream of the candidate HAR location.</td>
</tr>
<tr>
<td>AND</td>
</tr>
<tr>
<td>3. If there is a need to disseminate a detailed report (such as those possible using HAR recordings) as opposed to flashing beacons or DMS.</td>
</tr>
<tr>
<td>OR</td>
</tr>
<tr>
<td>4. If weather events contribute to a significant number of crashes or road closures such that there are major impacts to travelers (this may include 1 or more annual closures or crashes on an Interstate highway or 10 or more crashes or closures annually on arterials).</td>
</tr>
</tbody>
</table>

*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’.
### HAR Warrant #2: Venue Parking

**Purpose:**
To provide parking or route guidance information around major venues where unfamiliar travelers can benefit from verbal explanations (e.g. airports, National Parks, tourist attractions).

**Device is warranted if:**

1. The venue is visited by at least 10,000 visitors per day (either year-round or seasonally)
   
   **AND**
   
   Either 2a, 2b, or 2c

2a. If there are parking and drop-off/pick-up options that are not inherently simple enough to disseminate using static or DMS sign displays

   **OR**

2b. If there are parking options and real-time parking availability information available for dissemination

   **OR**

2c. If there are more than one primary access routes to the venue covered by the range of the HAR device (i.e. one HAR device would support all approaches vs. multiple signs being needed)

**Partial Warrant Criteria:**

If #2a, #2b, or #2c 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’.
<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To notify drivers in advance of special changing traffic conditions and roadway configurations associated with road construction or maintenance.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device is warranted if:</td>
<td>1. The candidate location is upstream of an area with traffic control changes (e.g. lane closure, crossover, contra flow) where travelers would benefit from a verbal explanation AND 2. If the candidate location is expected to encounter either long term construction or maintenance activities or changing traffic control situations for longer than 2 months</td>
</tr>
</tbody>
</table>

**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’.
### HAR Warrant #4: Special Events

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To notify travelers about special events (either prior to the event start date or during the event), alerting travelers to the impacts of these events on traffic, and to guide event attendees to the event.</th>
</tr>
</thead>
</table>
| Device is warranted if: | 1. The temporary event is expected to attract more than 600 vehicles in any one hour period.  
AND  
Either 2a. or 2b.  
2a. There is a route of travel for event attendees that creates considerably less impact on traffic than other approaches (i.e. if event attendees can be directed to this route it will minimize impacts).  
OR  
2b. There is an optional route for non-event traffic to avoid the impacts of this event.  
AND  
3. The message(s) that need to be relayed to the travelers are too complex to convey in a portable sign (better relayed through spoken reports). |
8.4 RWIS Warrants

RWIS refer to in-field atmospheric and/or road weather monitoring devices that are capable of measuring conditions and reporting conditions back to a central server or a roadside device.

Three (3) warrants have been identified to capture the most common uses of Road Weather Information Systems (RWIS). While there are other purposes and uses for RWIS, the warrants developed to date have focused on the following three.

R/WIS Warrant #1: Support Maintenance Activities at Key Locations
Purpose: To provide site specific atmospheric and road surface condition reports to the agencies responsible for responding to weather events in order to promote safe travel and maintain travelers’ mobility.

R/WIS Warrant #2: Support Regional, Statewide, or Provincial Weather Monitoring
Purpose: To monitor weather and road surface conditions on a regional, statewide, or provincial grid in order to support wide area weather monitoring and/or modeling and weather prediction.

R/WIS Warrant #3: Support Traveler Information Systems Through R/WIS at Key Locations
Purpose: To gather real-time data describing atmospheric weather and road surface conditions in order inform travelers of the conditions, either through pre-trip traveler information systems or through en-route information dissemination systems.
### RWIS Warrant #1: Support Maintenance Activities at Key Locations

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To provide site specific atmospheric and road surface condition reports to the agencies responsible for responding to weather events in order to promote safe travel and maintain travelers’ mobility.</th>
</tr>
</thead>
</table>
| Device is warranted if: | Either 1a, 1b, or 1c  
1a. The location surrounding the candidate site typically experiences 3 or more crashes related to weather events each year  
OR  
1b. The location surrounding the candidate site has experienced 1 or more fatalities per year in crashes related to weather events  
OR  
1c. The location surrounding the candidate site is prone to weather events frequently causing difficult driving conditions (e.g. treacherous roads in winter storms, seasonal or storm related flooding, pockets of fog)  
AND  
Either 2a or 2b  
2a. The number of weather events that would be measured and reported at the location is typically more than 10 per year  
OR  
2b. The area surrounding the site experiences rare weather events that cause serious operational problems that often last multiple days (e.g. one major ice storm)  
AND  
3. There is not another weather and road surface monitoring station that provides access to the data within 10 miles of the candidate site |
**Note:**
In using the warrants, it is recommended that the agency research whether any other agencies (National Park System, Department of Natural Resources, Department of Aviation) has weather and/or road condition monitoring stations and make the data publicly available.
## RWIS Warrant #2: Support Regional, Statewide, or Provincial Weather Monitoring

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To monitor weather and road surface conditions on a regional, statewide, or provincial grid in order to support wide area weather monitoring and/or modeling and weather prediction.</th>
</tr>
</thead>
</table>
| Device is warranted if: | 1. The candidate region, state, or province typically encounters 10 or more inclement weather events each year  

AND  

2a. The transportation agency responsible for maintenance in the region, state, or province has (or is planning) the ability to utilize grid weather reports (either manually or with the help of a decision support system) to influence their treatment of conditions  

OR  

2b. The transportation agency responsible for traveler information in the region, state, or province operates (or is planning to operate) a region-wide traveler information system including weather reports throughout the area  

AND  

3. The transportation agency responsible for maintenance and the agency responsible for traveler information in the region has examined and/or tested current perpetual data sources (e.g. NWS) and determined that these sources do not fully meet the needs for the region. |
<table>
<thead>
<tr>
<th>RWIS Warrant #3: Support Traveler Information Systems Through R/WIS at Key Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Purpose:</strong> To gather real-time data describing atmospheric weather and road surface conditions in order inform travelers of the conditions, either through pre-trip traveler information systems or through en-route information dissemination systems.</td>
</tr>
<tr>
<td><strong>Device is warranted if:</strong></td>
</tr>
<tr>
<td>1. The number of crashes related to weather events in the area surrounding the RWIS site (roughly 20 mile radius) is more than 5 per year</td>
</tr>
<tr>
<td>AND</td>
</tr>
<tr>
<td>2. If there are unique geography conditions at the site that prohibit the prediction of accurate weather from such systems as NWS forecasts</td>
</tr>
<tr>
<td>AND</td>
</tr>
<tr>
<td>Either 3a, 3b, or 3c</td>
</tr>
<tr>
<td>3a. The area in consideration is prone to fog or other local (non regional) visibility restrictions (defined as 10 or more events per year where fog presents dangerous driving conditions)</td>
</tr>
<tr>
<td>OR</td>
</tr>
<tr>
<td>3b. The area in consideration is near an attraction or other draw (winter recreation area, college, resort area) that attracts visitors traveling at least 1 hour to reach the destination</td>
</tr>
<tr>
<td>OR</td>
</tr>
<tr>
<td>3c. The area is along a regular commuter path.</td>
</tr>
</tbody>
</table>
8.5 Variable Speed Limit Warrants

For purposes of the warranting ITS process, Variable Speed Limit (VSL) devices are defined as signs capable of displaying different speed limits to travelers (in which the speed limit is either a recommended or mandatory limit) that are either manually activated or controlled by a combination of detectors and algorithms to select appropriate speeds.

Four (4) warrants have been identified to capture the most common uses of Variable Speed Limit devices. While there are other purposes and uses for VSL, the warrants developed to date have focused on the following four.

VSL Warrant #1: Maximize Capacity
Purpose: To maximize capacity by maintaining uniform travel speeds that are optimal for the current volume of traffic, and prevent the system from becoming ‘unstable’ and reaching congested conditions.

VSL Warrant #2: Safe Stopping Distances
Purpose: To encourage travel at speeds that are conducive to stopping safely for stopped vehicles (e.g. crashes, stalls, other incidents).

VSL Warrant #3: Safe Travel Speeds for Conditions
Purpose: To maintain safe travel speeds during periods when road and/or driving conditions may be impacted.

VSL Warrant #4: Work Zones
Purpose: To post varying speed limits for construction zones in order to only slow traffic when necessary, or to maintain consistent speeds to promote safety.
**VSL Warrant #1: Maximize Capacity**

| Purpose: | To maximize capacity by maintaining uniform travel speeds that are optimal for the current volume of traffic, and prevent the system from becoming ‘unstable’ and reaching congested conditions. |
| Device is warranted if: | |
| 1. The typical peak hour volume of the corridor exceeds 1,100 vphpl. | |
| 2. The route segment has a history of reduced speeds of 40 mph or less for a least one hour on typical days (55 mph posted speed). | |
| 3. There is a regularly occurring speed differential of at least 10 mph *(The 2009 MUTCD identifies roadway signs for all speed differentials in which the speed limit is reduced by 10 mph or more, therefore this value is used for the Warrants threshold)* between the upstream and downstream locations of the segment (e.g. a downstream bottleneck location has typical speeds that are slower than an upstream location). (1) |

---

*Warrants for ITS Devices: Phase 1 and 2 – Final Report
Version 1.6 – May 14, 2010*
**VSL Warrant #2: Safe Stopping Distances**

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To encourage travel at speeds that are conducive to stopping safely for stopped vehicles (e.g. crashes, stalls, other incidents).</th>
</tr>
</thead>
</table>
| **Device is warranted if:** | 1. The peak hour volume exceeds 1100 vphpl.  
AND  
2. The rear-end crash rate for the segment is higher than expected for the local area, based upon the judgment of local engineers.  
AND  
3. It has been observed that there is a significantly higher rate of secondary crashes on the candidate segment than other segments in the metropolitan area.  
AND  
4. There is a regularly occurring significant speed differential of at least 10 mph (*The 2009 MUTCD identifies roadway signs for all speed differentials in which the speed limit is reduced by 10 mph or more, therefore this value is used for the Warrants threshold*) between the upstream and downstream locations of the segment (e.g. a downstream bottleneck location has typical speeds that are slower than an upstream location). (1) |
### VSL Warrant #3: Safe Travel Speeds for Conditions

<table>
<thead>
<tr>
<th><strong>Purpose:</strong></th>
<th>To maintain safe travel speeds during periods when road and/or driving conditions may be impacted.</th>
</tr>
</thead>
</table>
| **Device is warranted if:** | 1. The area in consideration is a stretch of road (typically a minimum of 2 miles or longer) and not an isolated spot location (such as a bridge or a vertical curve) where other technologies may be more appropriate. AND  
2. The area regularly experiences adverse conditions (e.g. snow, water on the road, fog, wind, blowing snow, animal migrations) that result in traffic problems, slow downs, low visibility or safety hazards for travelers. OR  
The area experiences rare conditions that result in traffic problems, but the resulting traffic problems are known to impact large numbers of vehicles (e.g. locations with crashes that occur every 1-2 years but cause very large traffic pileups, impacting numerous vehicles). OR  
The geography or geometry of the area pose a known risk for traffic problems when traveled by vehicles at varying speeds. AND  
3. The crash rate for the segment or corridor is higher than expected for similar segments within the state, based upon the judgment of local engineers. For example: is the stretch of road a known location for high crash rates. AND  
4. The area experiences regular speed differentials of at least 10 mph *(The 2009 MUTCD identifies roadway signs for all speed differentials in which the speed limit is reduced by 10 mph or more, therefore this value is used for the Warrants threshold)* between drivers that are believed to contribute to crashes. (Speed differentials may be due to vehicles traveling slow for various reasons (e.g. commercial vehicles with chains limiting speed, cautious or unfamiliar drivers traveling considerably slower than other drivers), weather conditions that may not be obvious to all travelers (black ice, freezing conditions, water on the roadway, fog, heavy winds, blowing dust), or other factors). |
### VSL Warrant #4: Work Zones

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To post varying speed limits for construction zones in order to only slow traffic when necessary, or to maintain consistent speeds to promote safety.</th>
</tr>
</thead>
</table>
| Device is warranted if: | 1. The schedule of the construction activities being performed AND the design of the work zone are such that the vehicles are not required to be slowed to the same speed 24 hours per day. For example, if vehicles are slowed to a speed during the day when workers are present, but when work is not occurring the absence of workers and layout of the construction zone (lane width, geometries, structure) would allow higher speeds.  

OR  

The planned construction activities and design of the work zone will create varying conditions for travelers during the period of construction (e.g. periods when the safe speed will change, periods when travel lanes will change, anticipated geometry changes).  

OR  

The construction zone already exists and there is a noticeable differential in the speed of vehicles as they progress through the work zone (where travelers would benefit from slowing earlier).  

*Note: Many locations include additional fines for speeding in work zones, and the design of any variable speed limit system must consider this aspect before determining if variable speed systems are appropriate for work zones.*
8.6 Dynamic Speed Display Signs Warrants

For the purposes of the warranting process, Dynamic Speed Display Signs (DSDS) are defined as permanent or temporary signs that detect and display a vehicle’s current speed to the driver, often the speed display flashes if the vehicle is exceeding the speed limit. Dynamic Speed Display Signs are also commonly referred to as ‘Your speed is’ signs, or ‘Driver Feedback Signs’.

Three (3) warrants have been identified to capture the most common uses of Dynamic Speed Display Signs (DSDS) devices. While there are other purposes and uses for DSDS, the warrants developed to date have focused on the following three.

**DSDS Warrant #1: Transition Zones**
Purpose: To promote speed limit adherence in locations of speed limit reduction zones.

**DSDS Warrant #2: Posted Speed Adherence**
Purpose: To promote speed limit adherence in locations prone to vehicles exceeding the speed limit.

**DSDS Warrant #3: Intelligent Work Zones**
Purpose: To promote speed adherence in locations where posted speeds have temporarily been reduced for construction, maintenance or other traffic control.
### DSDS Warrant #1: Transition Zones

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To promote speed limit adherence in locations of speed limit reduction zones.</th>
</tr>
</thead>
</table>
| Device is warranted if: | 1. The 85th percentile speed (as determined by a speed study) at a location within the lower speed limit area exceeds the posted speed limit by at least 5 mph. (2) AND  
2. The zone experiences a posted speed limit reduction of at least 10 mph. AND  
3. There are no other Dynamic Speed Display Signs along the route encountering the speed transition, within 5 miles in either direction (excluding DSDS within school zones). (3)  

*Note: Signs tend to be most effective where there are two lanes or less in one direction of travel.*
<table>
<thead>
<tr>
<th>DSDS Warrant #2: Posted Speed Adherence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Purpose:</strong></td>
</tr>
<tr>
<td>To promote speed limit adherence in locations prone to vehicles exceeding the speed limit.</td>
</tr>
<tr>
<td><strong>Device is warranted if:</strong></td>
</tr>
<tr>
<td>1. The 85% speed (as determined by a speed study) exceeds the posted speed limit by at least 5 mph, or by at least 3 mph in a school zone. (4) (2) AND</td>
</tr>
<tr>
<td>2. The area is within 500 yards of a major pedestrian generator (e.g. school, park, library, senior center, office building). (5) OR</td>
</tr>
<tr>
<td>The area is primarily a residential area or a heavily traveled pedestrian area. (5) AND</td>
</tr>
<tr>
<td>3. The posted speed limit is 35 mph or less. (4) AND</td>
</tr>
<tr>
<td>4. There are no other Dynamic Speed Display Signs along the route within a 5 mile in either direction of the proposed sign (excluding DSDS within school zones). (3)</td>
</tr>
</tbody>
</table>

*Note: Signs tend to be most effective where there are two lanes or less in one direction of travel.*
### DSDS Warrant #3: Intelligent Work Zones

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To promote speed adherence in locations where posted speeds have temporarily been reduced for construction, maintenance or other traffic control.</th>
</tr>
</thead>
</table>
| **Device is warranted if:** | 1. The work zone is currently in operation and observations suggest that the 85th percentile speed at a location within the work zone exceeds the posted speed limit by at least 5 mph.  

OR  

Workers will be located adjacent to the open traffic lane.  

OR  

Hazardous roadway conditions, such as a temporary unusually tight curve, or a rough road surface, requiring extra driving precaution.  

*Note: Signs tend to be most effective where there are two lanes or less in one direction of travel.* |
8.7 Ramp Meter Warrants

Ramp Meters are defined by the Manual on Uniform Traffic Control Devices as traffic control signals that control the flow of traffic entering a freeway facility.

Three (3) warrants have been identified to capture the most common uses of Ramp Meters. While there are other purposes and uses for Ramp Meters, the warrants developed to date have focused on the following three.

Ramp Meter Warrant #1: Corridor-wide Ramp Meter Deployment
Purpose: This Warrant addresses the need for a ‘zone’ of Ramp Meters along a stretch of freeway (typically considered in 3-6 mile segments).

Ramp Meter Warrant #2: Isolated Ramp Meter Deployment
Purpose: This Warrant addresses the need for an isolated Ramp Meter deployment, that is not part of an overall corridor ramp metering approach.

Ramp Meter Warrant #3: Ramp Metering During Work Zone Activity
Purpose: To meter on-ramp traffic during road work activities to improve safety and/or consistent traffic flow.
### Ramp Meter Warrant #1: Corridor-wide Ramp Meter Deployment

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>This Warrant addresses the need for a ‘zone’ of Ramp Meters along a stretch of freeway (typically considered in 3-6 mile segments).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Device is warranted if:</strong></td>
<td></td>
</tr>
</tbody>
</table>
1. **Control Factors.** During the AM or PM Peak Period, the Zone in consideration has at least 30 minutes per commute day (measured in 5 minute increments) where the demand is equal to or exceeds 95% of the downstream capacity, according to the following equation?

\[
MV + OR > (ER + MC) \times .95
\]

Where:

- \( MV \) = Upstream Mainline Volume (in veh/5 min.)
- \( OR \) = The sum of On-Ramp volumes of ramps within the zone (in veh/5 min.)
- \( ER \) = The sum of Exit Ramp Volumes within the zone (in veh/5 min.)
- \( MC \) = Downstream Mainline Capacity (in veh/5 min.)

OR

Platoons from signalized intersections are recognized to adversely impact ALL on-ramps feeding the freeway segment under consideration. For example if hourly volume, based on maximum 30 second volume readings projected to hourly volumes, exceed 1100 vph. (regardless of overall hourly volume).

*Note: Overall hourly volume entering from arterials may be relatively low (e.g. 700 vph. However, during periods when platoons arrive, if 30 second readings of volumes represent 1100 vph or greater, this factor is considered met.*

AND

2. **Safety Factors.** There is one or multiple area(s) within the zone where crashes are understood to exceed the typical crash rate (at the ramp gore point or within 500 feet in either direction of the gore point) for the metropolitan area. (6)

AND

3. **Functionality Factors.** Volumes at ramps being considered for meters, within the zone, fall within the range of 240 – 900 vphpl during peak periods. (7)
### Ramp Meter Warrant #2: Isolated Ramp Meter Deployment

**Purpose:** This Warrant addresses the need for an isolated Ramp Meter deployment, that is not part of an overall corridor ramp metering approach.

**Device is warranted if:**

1. The freeway operates at speeds less than 50 mph for a duration of at least 30 minutes for 200 or more calendar days per year. (6)
   
   OR
   
   There is a high frequency of crashes (collision rate along the freeway exceeds mean collision rate in the subject metropolitan area) near the freeway entrances because of inadequate merge area or congestion? (6)
   
   OR
   
   The ramp meter will contribute to maintaining a specific level of service (LOS) identified in local transportation plans and policies. (6)
   
   OR
   
   The ramp meter will contribute to maintaining a higher level vehicle occupancy through the use of HOV preferential treatments as identified in the region’s transportation system management (TSM) plan. (6)
   
   OR
   
   The ramp meter will contribute to balancing demand and capacity at a system of adjacent ramps entering the same freeway facility. (6)
   
   OR
   
   The ramp meter will mitigate predictable sporadic congestion on isolated sections of freeway because of short peak period loads from special events or from severe peak loads of recreational traffic. (6)
   
   **AND**

2. The Total Mainline-Ramp Design Hour Volume (mainline volume plus ramp volume) exceeds the following: (8)
   
   - Two mainline lanes in one direction – 2,650 (vph);
   - Three mainline lanes in one direction – 4,250 vph;

---

1 The majority of the isolated intersection ramp meter warrant was originally developed by ITS Engineering and Constructors, Inc. on behalf of Arizona Department of Transportation, published as ‘Ramp Meter Design, Operations, and Maintenance Guidelines’.
- Four mainline lanes in one direction – 5,850 vph;
- Five mainline lanes in one direction – 7,450 vph;
- Six mainline lanes in one direction – 9,050 vph.

OR

The total volume of the sum of traffic in the right most lane and the ramp exceed 2100 vph during the design hour. (8)

OR

Platoons from signalized intersections are recognized to adversely impact the ramp in consideration. If hourly volume, based on maximum 30 second volume readings projected to hourly values, exceed 1100 vph. (regardless of overall hourly volume). (9)

*Note: Overall hourly volume entering from arterials may be relatively low (e.g. 700 vph). However, during periods when platoons arrive, if 30 second readings of volumes represent 1100 vph or greater, this factor is considered met.*

AND

3. *Functionality Factors.* Volumes at ramps being considered for meters, within the zone, fall within the range of 240 – 900 vphpl during peak periods. (7)

*Note: The length and geometry of the ramp is a factor in the final decision of whether to deploy a ramp meter. The current warrant for ramp meters does not address this factor, as it is believed the analysis of the ramp will be a part of the preliminary and final design. The focus of the warrant is on whether or not a ramp meter is needed (warranted), not on whether a ramp meter can be designed at the location, as that would be determined during the design process.*
<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To meter on-ramp traffic during road work activities to improve safety and/or consistent traffic flow.</th>
</tr>
</thead>
</table>
| Device is warranted if: | 1. *Capacity Factors.* There is a temporary reduction in capacity of through lanes due to either a reduction in the number of lanes, or a reduction in the width of lanes of traffic, causing a backup of traffic during peak periods.  

OR  

*Geometric Factors.* There is a temporary change in the geometry or length of the acceleration lane that will potentially have a negative impact on ramp traffic merging with the mainline traffic.  

OR  

*Behavior Factors.* There is a desire to discourage the use of the ramp during the period of road work. |
8.8 Curve Warning System Warrants

Curve Warning Systems are defined as a collection of devices deployed with the goal of reducing vehicle crashes and roadway departures within horizontal curves. Technology devices may include real-time warning signs triggered by vehicle factors (e.g. speed, height, weather) and/or roadway conditions (snow, ice, and rain) at approaches to sharp curves.

Three (3) warrants have been identified to capture the most common uses of Curve Warning System Devices. While there are other purposes and uses for Curve Warning Systems, the warrants developed to date have focused on the following three.

**Curve Warning System Warrant #1: Rural Two-Lane Highway Curves**
Purpose: To provide additional warnings beyond static advisory curve warning signs to warn drivers of actions required to reduce risks associated with rural two lane curves.

**Curve Warning System Warrant #2: High Risk Locations**
Purpose: To influence driver behavior in horizontal curves where an excessive level of crashes is occurring.

**Curve Warning System Warrant #3: Truck Rollovers on Ramps**
Purpose: To influence the behavior of commercial vehicle operators driving on ramps.
### Curve Warning System Warrant #1: Rural Two-Lane Highway Curves

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To provide additional warnings beyond static advisory curve warning signs to warn drivers of actions required to reduce risks associated with rural two lane curves.</th>
</tr>
</thead>
</table>
| **Device is warranted if:** | 1. The Radius of Curvature is less than 1,000 ft. *Research conducted by Texas Transportation Institute found the risk of crashes on curves increases significantly when the radius of curvature is less than 1,000ft.* (10)

**AND**

2. The horizontal curve is considered part of a visual trap (i.e. the beginning of the horizontal curve immediately follows a vertical curve and is hidden from the line of sight, or where the main road curves but a minor road (and sometimes utility lines) continue on the tangent). (11)

**OR**

There is an observed pattern of vehicles entering the curve at speeds that are faster than safe speeds. For example, the 85<sup>th</sup> percentile speed exceeds the recommended or posted speed limit.

**OR**

There are typically 2 or crashes on the curve each year. (12)

*Note: if there has been at least one crash in the last year on the horizontal curve, a lower technology solution may be appropriate. Freeborn County (Minnesota) Safety Study identified high risk curves to have a combination of a visual trap, a low radius of curvature and at least one previous crash.* (11)

**AND**

3. The highway is a 2-lane highway (1 lane each direction). (11)

**AND**

4. The Speed Limit on the Highway is 55 MPH or greater. (11)

**OR**

The Speed Differential (difference between the regulatory speed limit and the advisory speed limit) is 25 MPH or greater. (10)
## Curve Warning System Warrant #2: High Risk Locations

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To influence driver behavior in horizontal curves where an excessive level of crashes are occurring.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Device is warranted if:</strong></td>
<td></td>
</tr>
<tr>
<td>1. <strong>Crash Rate Factor.</strong> The Crash Rate (crashes per million vehicle miles traveled) within the vicinity of the curve exceeds 1 crash per million vehicle miles traveled, when computed over a 3 year period.</td>
<td></td>
</tr>
<tr>
<td>Calculation: CR = (# of crashes * 10⁶)/(Length * ADT<em>365Days</em>3 years). (13)</td>
<td>OR</td>
</tr>
<tr>
<td>The Curve has been identified as a location with a high probability for crashes, using the locally accepted crash analysis (e.g. one of the top 10 locations in the state most prone to curve related accidents, or on a list of areas most prone to crashes).</td>
<td>AND</td>
</tr>
<tr>
<td>2. <strong>Speed Factor.</strong> The number of vehicles that has been observed to enter the curve at speeds that are considered unsafe is more than expected, based on the judgment of local engineers. (e.g., high profile vehicles entering rural curves at speeds believed to be unsafe).</td>
<td>OR</td>
</tr>
<tr>
<td>There is evidence of near misses and/or rapid deceleration either within the curve or in the approach to the curve. (e.g. pavement skid marks, scrapes along guard rails)</td>
<td></td>
</tr>
</tbody>
</table>
## Curve Warning System Warrant #3: Truck Rollovers on Ramps

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To influence the behavior of commercial vehicle operators driving on ramps.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Device is warranted if:</strong></td>
<td></td>
</tr>
<tr>
<td>1. <strong>Crash Rate Factor.</strong> The Curve has a history of at least one truck rollover crash every 5 years. (12)</td>
<td>AND</td>
</tr>
<tr>
<td>2. <strong>Speed Factor.</strong> Vehicles have been observed to enter the curve at speeds that are unsafe. (e.g. trucks entering ramps at unsafe speeds).</td>
<td>OR</td>
</tr>
<tr>
<td></td>
<td>There is evidence of near misses and/or rapid deceleration either within the curve or in the approach to the curve. (e.g. pavement skid marks, scrapes along guard rails)</td>
</tr>
</tbody>
</table>
8.9 Intelligent Work Zone Warrants

Intelligent Work Zones are defined as a collection of devices that collectively warn travelers of various hazards associated with work zones.

Six (6) warrants have been identified to capture the most common uses of Intelligent Work Zone Devices. While there are other purposes and uses for Intelligent Work Zones as well as existing system components to consider, the warrants developed to date have focused on the following six.

DMS Warrant #3: Changing Traffic Condition (WARRANT FROM PHASE 1)
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.

CCTV Warrant #6: Intelligent Work Zone
Purpose: To allow travelers or transportation professionals to understand construction or maintenance traffic delay by viewing images of the roadway remotely.

HAR Warrant #3: Changing Traffic Conditions (WARRANT FROM PHASE 1)
Purpose: To notify drivers in advance of special changing traffic conditions and roadway configurations associated with road construction or maintenance.

VSL Warrant #4: Work Zones (WARRANT FROM PHASE 2)
Purpose: To post varying speed limits for construction zones in order to only slow traffic when necessary, or to maintain consistent speeds to promote safety.

DSDS Warrant #3: Intelligent Work Zones (WARRANT FROM PHASE 2)
Purpose: To promote speed adherence in locations where posted speeds have temporarily been reduced for construction, maintenance or other traffic control.

Ramp Meter Warrant #3: Ramp Metering During Work Zone Activity (WARRANT FROM PHASE 2)
Purpose: To meter on-ramp traffic during road work activities to improve safety and/or consistent traffic flow.
### DMS Warrant #3: Changing Traffic Condition (WARRANT FROM PHASE 1)

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>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.</th>
</tr>
</thead>
</table>
| **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. If 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. If 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’.
### CCTV Warrant #6: Intelligent Work Zone

<table>
<thead>
<tr>
<th><strong>Purpose:</strong></th>
<th>To allow travelers or transportation professionals to understand construction or maintenance traffic delay by viewing images of the roadway remotely.</th>
</tr>
</thead>
</table>
| **Device is warranted if:** | 1. The alignment or traffic control that is visible by a camera image is expected to change periodically during the construction period.  
OR  
The construction zone encounters periods of queues or delays for at least 30 minutes each day.  
AND  
2. The construction zone is in a location where there is not a convenient alternate route for the majority of traffic to deviate from the typical route. |
### HAR Warrant #3: Changing Traffic Conditions (WARRANT FROM PHASE 1)

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To notify drivers in advance of special changing traffic conditions and roadway configurations associated with road construction or maintenance.</th>
</tr>
</thead>
</table>
| Device is warranted if: | 1. The candidate location is upstream of an area with traffic control changes (e.g. lane closure, crossover, contra flow) where travelers would benefit from a verbal explanation;  

AND  

2. If the candidate location is expected to encounter either long term construction or maintenance activities or changing traffic control situations for longer than 2 months;  

**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’. |
# VSL Warrant #4: Work Zones (WARRANT FROM PHASE 2)

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To post varying speed limits for construction zones in order to only slow traffic when necessary, or to maintain consistent speeds to promote safety.</th>
</tr>
</thead>
</table>
| **Device is warranted if:** | 1. The schedule of the construction activities being performed AND the design of the work zone are such that the vehicles are not required to be slowed to the same speed 24 hours per day. For example, if vehicles are slowed to a speed during the day when workers are present, but when work is not occurring the absence of workers and layout of the construction zone (lane width, geometries, structure) would allow higher speeds.  
OR  
2. The planned construction activities and design of the work zone will create varying conditions for travelers during the period of construction (e.g. periods when the safe speed will change, periods when travel lanes will change, anticipated geometry changes).  
OR  
3. The construction zone already exists and there is a noticeable differential in the speed of vehicles as they progress through the work zone (where travelers would benefit from slowing earlier).  

*Note: Many locations include additional fines for speeding in work zones, and the design of any variable speed limit system must consider this aspect before determining if variable speed systems are appropriate for work zones.*
### DSDS Warrant #3: Intelligent Work Zones (WARRANT FROM PHASE 2)

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To promote speed adherence in locations where posted speeds have temporarily been reduced for construction, maintenance or other traffic control.</th>
</tr>
</thead>
</table>
| Device is warranted if: | 1. The work zone is currently in operation and observations suggest that the 85th percentile speed at a location within the work zone exceeds the posted speed limit by at least 5 mph.  
OR  
Workers will be located adjacent to the open traffic lane.  
OR  
Hazardous roadway conditions, such as a temporary unusually tight curve, or a rough road surface, requiring extra driving precaution. 

*Note: Signs tend to be most effective where there are two lanes or less in one direction of travel.*
<table>
<thead>
<tr>
<th><strong>Ramp Meter Warrant #3: Ramp Metering During Work Zone Activity (WARRANT FROM PHASE 2)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Purpose:</strong> To meter on-ramp traffic during road work activities to improve safety and/or consistent traffic flow.</td>
</tr>
<tr>
<td><strong>Device is warranted if:</strong></td>
</tr>
</tbody>
</table>
| 1. **Capacity Factors.** There is a temporary reduction in capacity of through lanes due to either a reduction in the number of lanes, or a reduction in the width of lanes of traffic, causing a backup of traffic during peak periods.  
   OR  
   2. **Geometric Factors.** There is a temporary change in the geometry or length of the acceleration lane that will potentially have a negative impact on ramp traffic merging with the mainline traffic.  
   OR  
   3. **Behavior Factors.** There is a desire to discourage the use of the ramp during the period of road work. |
5. SYSTEMS ENGINEERING PROCESS

The International Council of Systems Engineers uses the following definition for “Systems Engineering”:

*Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem:*

- Operations
- Cost & Schedule
- Performance
- Training & Support
- Test
- Manufacturing
- Disposal

*Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.*

ITS projects shall conform to the National ITS Architecture and Standards and development of the regional ITS architecture should be consistent with the transportation planning process. ITS projects funded with highway trust funds shall be based on a systems engineering analysis. Which should result in the final design of all ITS projects funded with highway trust funds shall be consistent with the regional ITS architecture.

The information on the following pages is a handout from Chapter 3 of “Systems Engineering for Intelligent Transportation Systems – An Introduction for Transportation Professionals”. The information can be found by going to:


All projects funded with highway trust fund monies must conform with the National ITS Architecture and standards and use the System Engineering Process.
3 WHAT IS SYSTEMS ENGINEERING?

3.1 A Few Definitions

In true systems engineering fashion, let’s begin with a few basic definitions before we jump into the details of the systems engineering discipline.

What is a System?

Everyone uses the term and has an intuitive notion of what a system is, but there is a formal definition. INCOSE defines a system as:

“A combination of interacting elements organized to achieve one or more stated purposes.”

This general definition covers almost everything you can think of – household appliances, transportation management systems, the latest weapon system – all of these are systems.

What is Systems Engineering?

Since the term was coined in the 1950s, systems engineering has evolved from a process focused primarily on large-scale defense systems to a broader discipline that is used in all kinds of project development. Systems engineering can be applied to any system development, so whether you are developing a household appliance, building a house, or implementing a sophisticated transportation management system, systems engineering can be used. INCOSE defines systems engineering like this:

Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem.

Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Note that this definition is very broad – it covers the project life cycle from needs definition to system disposal. It includes technical activities like requirements and design, as well as project activities like risk management and configuration management. Systems engineering provides a systematic process and tools that directly support project management.

What is an ITS Project?

In order to apply systems engineering to ITS projects in accordance with the FHWA Rule/FTA Policy, it is important to define an ITS project. Rule 940 defines ITS projects quite broadly:

ITS Project means any project that in whole or in part funds the acquisition of technologies or systems of technologies that provide or significantly contribute to the provision of one or more ITS user services as defined in the National ITS Architecture.

This definition encompasses a wide range of projects. Smaller ITS projects might be limited to the purchase and installation of field equipment – controllers, ramp meters,
signals, etc. Larger ITS projects support integration of multiple systems and development of custom software – for example, transportation management centers and 511 traveler information systems. These ITS projects are vastly different in complexity and in the amount of systems engineering that is needed. The FHWA Division/FTA Regional Offices establish and monitor how systems engineering analysis requirements are levied on specific ITS projects.

3.2 Key Principles

There are a handful of fundamental challenges and important concepts that shape and drive the systems engineering discipline.

3.2.1 Project Development Challenges

Project Initiation Euphoria

In the first days of any new project, the mood is optimistic and expectations are high. Just over the horizon, reality is looming, and technology, schedule, and funding constraints may ultimately cause the project to fall short of goals that were established in its early days. The need to balance these natural inclinations and real-world constraints is an important driver for implementing a systematic systems engineering approach at the outset to guide the team and manage expectations.

Cone of Uncertainty

At the beginning of a high-technology project, there may also be significant uncertainty in the project cost and schedule estimates. The less experience the project team has with similar projects, the more uncertainty there will be. The estimates naturally get better as work progresses and the project team gains a better understanding of the system they are building. At project completion, all the uncertainty has been removed – the team knows exactly how much was spent. When you plot the uncertainty against time (see Figure 4), it looks like a cone, which is why Barry Boehm called this challenge the “cone of uncertainty”.

Systems engineering focuses on resolving uncertainty early in project development by establishing the project scope and defining good requirements. Incremental development strategies also help to mitigate the risk of unreliable estimates early in the project.

Figure 4: Cone of Uncertainty
The Wrong Procurement Method Can Tie Your Hands

The traditional procurement methods that have been used for decades in highway construction are often not suitable for ITS projects. For example, the Low Bid method uses a consultant to prepare a design specification that is then implemented by a contractor who submits the lowest bid. This method works well for building roads, but experience shows that it does not work well for many ITS projects that frequently require collaboration and iteration between the design and implementation phases. It is vital to select the right procurement method so that you can implement the right systems engineering approach for your project. (See Section 6.2.1 for more information on procurement.)

Late Changes Drive Project Costs

There is no such thing as a mistake-free project development. In the transportation industry, experienced construction managers will tell you that every project has change orders. The problem is that change orders during construction are more expensive to the project. A mistake or missed system feature that is not recognized until after project closeout will be even more expensive to address.

Studies\(^5\) of software development projects have shown that this “latency cost” can increase the cost of fixing a mistake dramatically. As shown in Figure 5, for example, a bad requirement will be relatively cheap to fix while you are still in the requirements phase (1x) but increasingly expensive to fix later in project development. This is because you not only have to fix the bad requirement later in the project, you also have to fix the design and implementation problems that were caused by the bad requirement. The problems compound themselves if they are left uncorrected.

In systems engineering, verification and validation of the evolving project documentation is performed early and often to maximize the chances of identifying defects as early in the project development cycle as possible.

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The Odds Are Against Success

The Standish Group has done more than 10 years of research, collecting statistics on information technology projects, and their findings have consistently painted a dismal (albeit slowly improving) picture. For example, in 2004, as shown in Figure 6, only 34% of the projects surveyed met the criteria for success – completed on time, on budget, and with all the features originally specified. Of the 280,000 projects surveyed that year, more than 142,000 were late or over budget and another 42,000 failed outright.

Figure 6: Standish Group: 2004 CHAOS Report Project Success Rate

While the infamous failure rates are the most often repeated information, the report also identifies success factors that are identified through the same project surveys. Many of these success factors (including user involvement, minimized scope, and firm basic requirements) are related to the systems engineering process. Systems engineering won’t guarantee success, but it will help you to identify issues earlier in the project schedule and will improve your chances for a successful project in the end.

3.2.2 Systems Engineering Principles

Start with Your Eye on the Finish Line

You should reach consensus at the very beginning of the project on what will constitute success at the end. This means that the stakeholders should start with an agreement of what the project should accomplish and the metrics that will be used to measure the success of the project. This initial focus on the finish line must be sustained by project management as project development progresses and competing interests and project complexities begin to dominate the day-to-day work.

Stakeholder Involvement is Key

Successful projects involve the customer, users, operators, and other stakeholders in the project development. Systems engineering is a systematic process that includes reviews and decision points intended to provide visibility into the process and encourage stakeholder involvement. The systems engineering process includes stakeholders through all stages of the project, from initial needs definition through system verification and acceptance. The stakeholders who are involved in any particular step will vary, providing managers, operators, and technical personnel with an opportunity to contribute to the steps in the process where their input is needed.
Define the Problem Before Implementing the Solution

Very often, you’ll have a solution already in mind at the start of a project and may even find yourself “backing into” requirements to match your solution. Resist this temptation and instead use the systems engineering process to first define the problem. You’ll find that there are actually multiple ways to solve the problem, and a good trade study will help you to determine the best solution on the basis of a clear understanding of the requirements.

Delay Technology Choices

Technology is constantly changing. The choices available when a project is initially conceived may well be replaced by better technology by the time the project is implemented. Specifying technology too early will result in outdated technology or constant baseline changes as you try to keep up with technology advancements. It’s best to follow the systems engineering process by defining the needs, requirements, and high-level design without specifying technology. You’ll have a stable baseline, and you’ll be able to make the most appropriate technology choices when it is time to implement.

Baseline is a frequently used term in systems engineering. A baseline is a reference point against which everyone on the project team works, so you want to control the changes that are made to the baseline. The process of establishing and controlling project baselines is configuration management, which is discussed in Section 5.4.

Divide and Conquer

Many systems are large and complex. A key systems engineering strategy is the decomposition of such a system into smaller subsystems and then of the subsystems into more manageable hardware and software components. These simpler components are easier to understand and define and ultimately are easier to build. Much of the systems engineering process is built around this approach – breaking down a big problem into many smaller components that can be individually solved and then recombined.

Connecting the Dots – Traceability

As you move from one step to the next in the systems engineering process, it is important to be able to relate the items in one step with those in another. The relationship between items is called traceability. For example, you use traceability to relate a requirement to the subsystem that will implement the requirement. Traceability connects many items together. The requirement will be related to a user need as well as to a test that will be used to verify the requirement. Traceability is a powerful concept that allows you to be certain that the system that is implemented at the end of the project is directly connected with the user needs that were identified at the beginning.
3.3 The “V” Systems Engineering Model

Many different process models have been developed over the years that specify a series of steps that make up the systems engineering approach. Among these models, the “V” model, shown in Figure 7, is emerging as the de facto standard way to represent systems engineering for ITS projects.

Don’t be surprised if you come across different spellings for the “V” model. Some books, guides, and other resources refer to the same V-shaped model as the “Vee” model. If it looks like a “V” and it sounds like a “V”, then it is a reference to the same basic model, whether it is spelled “V” or “Vee”.

3.3.1 Overview of the “V” Model

Since it was first developed in the 1980s, the “V” model has been refined and applied in many different industries. Wings have been recently added to the “V” as part of its adaptation for ITS to show how project development fits within the broader ITS project life cycle. The left wing shows the regional ITS architecture, feasibility studies, and concept exploration that support initial identification and scoping of an ITS project based on regional needs. A gap follows the regional architecture(s) step because the regional architecture is a broader product of the planning process that covers all ITS projects in the region. The following steps in the “V” are for a specific ITS project. The central core of the “V” shows the project definition, implementation, and verification processes. The right wing shows the operations and maintenance, changes and upgrades, and ultimate retirement of the system. The wings are a key addition to the model since it is important to consider the entire life cycle during project development.

As shown in the “V”, the systems engineering approach defines project requirements before technology choices are made and the system is implemented. On the left side of the “V”, the system definition progresses from a general user view of the system to a detailed specification of the system design. The system is decomposed into subsystems, and the subsystems are decomposed into components – a large system may be broken into smaller and smaller pieces through many layers of decomposition. As the system is decomposed, the requirements are also decomposed into more specific requirements that are allocated to the system components.

As development progresses, a series of documented baselines are established that support the steps that follow. For example, a consensus Concept of Operations supports system requirements development. A baseline set of system requirements then supports system design. The hardware and software are implemented at the bottom of the “V”, and the components of the system are then integrated and verified in iterative fashion on the right. Ultimately, the completed system is validated to measure how well it meets the user’s needs. (Each of the steps in the “V” are defined in detail in Chapter 4.)

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Figure 7: Systems Engineering “V” Diagram
3.3.2 Connecting the Left and Right Sides of the “V”

One of the first things that strikes you about the “V” is the symmetry between the left and right sides of the model. This symmetry reflects the relationship between the steps on the left and the steps on the right. The system definition that is generated on the left is ultimately used to verify the system on the right. For example, the user needs and performance measures that are identified in the Concept of Operations are the basis for the System Validation Plan that is used to validate the system at the end of project development. Similarly, a System Verification Plan is developed with the System Requirements so that the engineers consider how to verify each requirement as the requirements are written.

The connections between the left and right are indicated by the arrows that cross the “V”, showing how plans developed on the left drive the process on the right. These connections provide continuity between the beginning and end of project development and ensure that the engineers are focused on the completion of the project from the beginning. The connections between the left and right sides of the model reflect one of the systems engineering principles – start with your eye on the finish line.

3.3.3 Decision Points

Projects have been managed for years using Gantt charts that identify tasks and major milestones. You don’t start the next task until you have completed the previous supporting tasks and passed the intervening milestone. The “V” diagram is similarly punctuated by a series of major milestones (labeled Document/Approval in the figure) where the output of the previous step is reviewed and the customer and project team determine whether the project is ready to move to the next step in the process. The project moves forward only if the criteria for the decision point have been satisfied. Decision points are important milestones that provide visibility into the project development and allow for issue identification and course correction during development. (Decision-point reviews are covered in more detail in Section 5.2.2.)
5.1 Regional ITS Architecture

The “Minnesota Statewide Regional ITS Architecture, Version 2009 -Volume 8: Regional ITS Architecture” states:

The Minnesota Statewide Regional ITS Architecture represents a shared vision of how each agency’s systems work together by sharing information and resources to enhance transportation safety, efficiency, capacity, mobility and security. The information exchange among the many transportation stakeholders helps illustrate various integration options, gain consensus on cost-effective ITS technologies and systems to be considered prior to investing in design, development and deployment of ITS.

The Minnesota Statewide Regional ITS Architecture is a living document and will evolve as needs, technology, stakeholders and funding change. The National ITS Architecture is a resource to the Minnesota Statewide Regional ITS Architecture providing framework for planning, defining and integrating ITS.

The Minnesota Statewide Regional ITS Architecture is organized as follows:

- **Volume 1 – Overview:** Volume 1 identifies the purpose/need, a general description of the region, development objectives, and performance measures for the Minnesota Statewide Regional ITS Architecture.

- **Volumes 2 thru 7 – Development and Documentation of Market Package Bundles:** Each volume will be specific to the corresponding Market Package Bundle and include: a description of the Market Package Bundle, ITS development objectives, a summary of needs and services, and a detailed description of needs and services (consisting of the operational concept, inventory, specific market packages to address needs and services, interconnects and architecture flows, and functional requirements).

- **Volume 8 – Regional ITS Architecture:** Volume 8 consists of the hard copies of the Turbo Architecture outputs and the corresponding electronic files.

- **Volume 9 – Regional ITS Architecture Implementation Projects:** This volume identifies an implementation project summary and corresponding project detail for each project. The project detail will include a project description, dependencies, time frame, project champion and any agency agreements required.

These volumes can be found by going to:

[www.dot.state.mn.us/guidestar/2006_2010/its_planning_and_regional_architecture.html](http://www.dot.state.mn.us/guidestar/2006_2010/its_planning_and_regional_architecture.html)
5.1.1 **ITS Architecture and System Engineering Checklist**

Rule 940 states (See Appendix B - 23 CFR Section 940)) that the systems engineering analysis shall identify, at a minimum:

- Portions of the regional ITS architecture being implemented
- Participating agencies roles and responsibilities
- Requirements definitions
- Alternative system configurations and technology options
- Procurement options
- Applicable ITS standards and testing procedures
- Procedures and resources necessary for operations and management of the system

The following handout is “Minnesota Statewide Regional ITS Architecture and Systems Engineering Checklist for ITS Projects - FHWA Final Rule 940 and FTA National ITS Architecture Policy”. Integration of the Checklist into the Minnesota Transportation Investment Program is recommended.

**WHEN:** Completion of this checklist will be required prior to FHWA/FTA funding authorization.

**HOW:** The following slides use a project as an example to fill out the checklist.

The checklist on the following pages is a handout from Chapter 9, Appendix B of “Minnesota Statewide Regional ITS Architecture, Volume 9: Regional ITS Architecture Implementation Projects”. The information can be found by going to: [www.dot.state.mn.us/guidestar/2006_2010/its_planning_and_regional_architecture.html](http://www.dot.state.mn.us/guidestar/2006_2010/its_planning_and_regional_architecture.html).
Appendix B
Minnesota Statewide Regional ITS Architecture and Systems Engineering Checklist for ITS Projects
FHWA Final Rule 940 and FTA National ITS Architecture Policy

For all ITS projects or projects with an ITS component, an Architecture Compliance Checklist must be completed and submitted with the Environmental Document. For questions regarding the completion of this checklist contact Rashmi Brewer, P.E. – Mn/DOT Office of Traffic, Safety and Technology at 651-234-7063 or e-mail at Rashmi.Brewer@dot.state.mn.us.

SECTION 1 – Project Information

1.1 CONTACT PERSON (e.g. PROJECT MANAGER)

Name: __________________ Title: ____________ Agency: ____________

Signature: ______________ Date: ____________

Telephone: ______________ Email: ____________

1.2 PROJECT TITLE

1.3 PROJECT NUMBER

1.3A Federal Project Number: ____________

1.3B State/Local Project Number: ____________

1.4 PROJECT LOCATION AND DESCRIPTION OF PROPOSED WORK

1.5 NEEDS ASSESSMENT

Please describe the problem statement, goals and objectives of the project.

How were these needs identified? (Check appropriate box(es))

☐ Internal Assessment  ☐ Stakeholder Involvement  ☐ Regional ITS Architecture

☐ Other ITS Planning or Technical Documents  ☐ Technical Reviews or other studies

If other documentation was used as a reference, please identify it here:

1.6 NATURE OF WORK (Check appropriate box(es))

☐ Scoping  ☐ Design  ☐ Software/Integration  ☐ Construction  ☐ Operations & Management

☐ Evaluations  ☐ Planning  ☐ Equipment Replacement  ☐ Research & Development

☐ Others (Please Specify)
1.7 RELATIONSHIP TO OTHER PROJECTS AND PHASES

Please list any construction and tied projects.

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<thead>
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<th>Project Title</th>
<th>Project Number</th>
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<tr>
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</tr>
</tbody>
</table>

SECTION 2 - Regional Architecture Assessment

2.1 PORTIONS OF REGIONAL ARCHITECTURE BEING IMPLEMENTED

- Archived Data Management (AD)
- Public Transportation (APTS – Advanced Public Transportation Systems)
- Traveler Information (ATIS – Advanced Traveler Information Systems)
- Traffic Management (ATMS – Advanced Traffic Management Systems)
- Vehicle Safety (AVSS – Advanced Vehicle Safety Systems)
- Commercial Vehicle Operations (CVO)
- Emergency Management (EM)
- Maintenance & Construction Management (MCM)

2.2 INVENTORY ELEMENTS IN MINNESOTA STATEWIDE REGIONAL ARCHITECTURE INCLUDED BY THIS PROJECT (Refer to Sections 4.3 and 4.4 of Volume 9 document for a list of projects included in the architecture)

Project is included in the Minnesota Statewide Regional ITS Architecture: ☐ Yes  ☐ No

If “No”, please list ITS elements included in this project.

2.3 INTERFACE IMPACTS (I.E. DATA EXCHANGES) DUE TO PROJECT

Turbo Architecture – “Market Package Report” ☐ Attached
Turbo Architecture – “Interconnect and Flow Diagrams/Reports” ☐ Attached
2.4 DOES THE DESIGN INCORPORATE NATIONAL ITS STANDARDS?
☐ No ☐ Yes
If “Yes”, please specify what ITS Standards are being used:

Turbo Architecture - “Standards Report” ☐ Attached
Information on ITS Standards can be found at http://www.standards.its.dot.gov/default.asp.

2.5 CHANGES RECOMMENDED TO MINNESOTA STATEWIDE REGIONAL ARCHITECTURE
☐ No ☐ Yes
If “Yes”, please specify and provide detail:

---

SECTION 3 - Project Matrix

3.1 PROJECT MATRIX - DOCUMENTATION

<table>
<thead>
<tr>
<th></th>
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<th>Existing To Be Modified</th>
<th>To Be Developed</th>
<th>Not Applicable</th>
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<td>Alternatives Analysis</td>
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<td>Concept of Operations</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
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<tr>
<td>Requirements</td>
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<td>System Test Plan</td>
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<tr>
<td>Evaluation</td>
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<td>[ ]</td>
<td>[ ]</td>
</tr>
</tbody>
</table>

Document Reference (file number or name)/Comments

SECTION 4 - Procurement

4.1 PROCUREMENT METHODS (Check all that apply)
☐ Construction Contract
☐ Professional Technical Services Contract/Agreement
☐ Joint Powers Contract/Agreement
☐ Interagency Contract/Agreement
☐ Work Order Contract/Agreement
☐ Commodities Contract
☐ Purchase Order
☐ Other

Comments:

SECTION 5 - Operations and Management
5.1 STAFFING AND RESOURCES NEEDED FOR OPERATIONS AND MANAGEMENT

5.2 ESTIMATED ANNUAL OPERATIONS AND MANAGEMENT COSTS

SECTION 6 - Schedule

6.1 EXPECTED PROJECT COMPLETION DATE

SECTION 7 - Agreements

7.1 IS AN INTERAGENCY AGREEMENT NEEDED FOR THIS PROJECT?
☐ Existing  ☐ To be Developed  ☐ No
Please describe: (Agency name, agreement number, and nature of contract)

SECTION 8 - Approval

APPROVAL
Name: ______________  Title: __________  Agency: __________
Signature: __________  Date: __________
Telephone: __________  Email: __________
5.2 Concept of Operations

The Concept of Operations:

- documents the total environment and use of the system to be developed in a non-technical and easy-to-understand manner
- presents this information from multiple viewpoints
- provides a bridge from the problem space and stakeholder needs to the system level requirements

See the handout on the following pages for additional details.

5.3 Requirements

Requirements are the foundation for building Intelligent Transportation Systems [ITS]. They determine WHAT the system must do and drive the system development. Requirements are used to determine [verify] if the project team built the system correctly. The requirements development process identifies the activities needed to produce a set of complete and verifiable requirements.

See the handout on the following pages for additional details.

5.4 Test and Acceptance Plans

The software and hardware components are individually verified and then integrated to produce higher-level assemblies or subsystems. These assemblies are also individually verified before being integrated with others to produce yet larger assemblies, until the complete system has been integrated and verified.

See the handout on the following pages for additional details.

5.5 Operations and Maintenance Plan

Once the customer has accepted the ITS system, the system operates in its typical steady state. System maintenance is routinely performed and performance measures are monitored. As issues, suggested improvements, and technology upgrades are identified, they are documented, considered for addition to the system baseline, and incorporated as funds become available. An abbreviated version of the systems engineering process is used to evaluate and implement each change. This occurs for each change or upgrade until the ITS system reaches the end of its operational life.

See the handout on the following pages for additional details.

The information on the following pages is a handout from Chapter 4 of “Systems Engineering for Intelligent Transportation Systems – An Introduction for Transportation Professionals”. The information can be found by going to:

4.3 Concept of Operations

In this step: The project stakeholders reach a shared understanding of the system to be developed and how it will be operated and maintained. The Concept of Operations (ConOps) is documented to provide a foundation for more detailed analyses that will follow. It will be the basis for the system requirements that are developed in the next step.

| OBJECTIVES | ▪ High-level identification of user needs and system capabilities in terms that all project stakeholders can understand
▪ Stakeholder agreement on interrelationships and roles and responsibilities for the system
▪ Shared understanding by system owners, operators, maintainers, and developers on the who, what, why, where, and how of the system
▪ Agreement on key performance measures and a basic plan for how the system will be validated at the end of project development |
| --- | --- |
| INPUT Sources of Information | ▪ Stakeholder lists, roles and responsibilities, and other components from the regional ITS architecture
▪ Recommended concept and feasibility study from the previous step
▪ Broad stakeholder input and review |
| PROCESS Key Activities | ▪ Identify the stakeholders associated with the system/project
▪ Define the core group responsible for creating the Concept of Operations
▪ Develop an initial Concept of Operations, review with broader group of stakeholders, and iterate
▪ Define stakeholder needs
▪ Create a System Validation Plan |
| OUTPUT Process Results | ▪ Concept of Operations describing the who, what, why, where, and how of the project/system, including stakeholder needs and constraints
▪ System Validation Plan defining the approach that will be used to validate the project delivery |
| REVIEW Proceed only if you have: | ▪ Received approval on the Concept of Operations from each stakeholder organization
▪ Received approval on the System Validation Plan from each stakeholder organization |
4.3.1 Overview

The Concept of Operations (ConOps) is a foundation document that frames the overall system and sets the technical course for the project. Its purpose is to clearly convey a high-level view of the system to be developed that each stakeholder can understand. A good ConOps answers who, what, where, when, why, and how questions about the project from the viewpoint of each stakeholder, as shown in Figure 12.

- **Who** – Who are the stakeholders involved with the system?
- **What** – What are the elements and the high-level capabilities of the system?
- **Where** – What is the geographic and physical extent of the system?
- **When** – What is the sequence of activities that will be performed?
- **Why** – What is the problem or opportunity addressed by the system?
- **How** – How will the system be developed, operated, and maintained?

In ITS, we draw a distinction between an Operational Concept, which is the high-level description of roles and responsibilities that is included in the regional ITS architecture, and a Concept of Operations, which is the more detailed, multifaceted document described in this section.

Don’t assume that a new ConOps is required for every ITS project. A single system-level ConOps can support many ITS projects that incrementally implement and extend a system. For example, a ConOps may be developed for a large transportation management system. This system may be implemented and expanded with numerous ITS projects over several years. Once the ConOps is developed, it may be reviewed and used with relatively minor updates for each of the projects that incrementally implement the transportation management system.

4.3.2 Key Activities

Although there is no single recipe for developing a ConOps, successful efforts will include a few key activities:

- **Identify the stakeholders associated with the system/project** – Systems engineering in general, and this effort in particular, require broad participation from the project’s stakeholders. One of the first steps in developing a ConOps is to make sure that all the stakeholders involved in or impacted by the project – owners, operators, maintainers, users, and so forth – are identified and involved. You can start with the stakeholder list from the regional ITS architecture and then expand it to identify the more specific organizations – divisions and departments – that should be involved. One of the most
effective ways to involve the stakeholders is to create an integrated product team (IPT) that brings together the necessary expertise and provides a forum for all project stakeholders.

- **Define the core group responsible for creating the ConOps** – Although broad involvement is critical, you can’t have 20 people on your writing team. Select a few individuals who are responsible for capturing and documenting the vision of the broader group. Depending on the size of the project and staff capabilities, this team might include a consultant or staff members with knowledge of the project and requisite writing and communications skills.

If you hire a consultant, don’t assume that is the end of your responsibility for ConOps development. The stakeholders are the foremost experts on their needs and must be materially involved in the ConOps development. The consultant can provide technical expertise on what should be in a ConOps, facilitate the meetings and outreach activities, prepare the document, and coordinate the review, but the stakeholders’ concept should be documented in the end. The stakeholders should consider the ConOps their document, not the consultant’s document.

The best person to write the ConOps may not be the foremost technical expert on the proposed system. Stakeholder outreach, consensus building, and the ability to understand and clearly document the larger picture are key.

- **Develop the initial ConOps, review it with the broader group of stakeholders, and iterate** – Incrementally create the ConOps, review relevant portions with stakeholders, and adjust the concept as necessary to get buy-in. All stakeholders do not have to agree on every aspect of the project, but all must feel that they are achieving their major goals for the project.

Portions of the ConOps can often be created from existing documents. For example, the regional ITS architecture identifies stakeholder roles and responsibilities that can be used. A feasibility study, project study report, or other preliminary study documentation may provide even more relevant information. A project application form used to support project programming will normally include goals, objectives, and other information that should be reflected in the ConOps for continuity.

Operational scenarios are an excellent way to work with the stakeholders to define a ConOps. Scenarios associated with a major incident, a work zone, or another project-specific situation provide a vivid context for a discussion of the system’s operation. It is common practice to define several scenarios that cover normal system operation (the “sunny day” scenario) as well as various fault-and-failure scenarios.

- **Define stakeholder needs** – Actually, this is a key purpose of the ConOps – to capture a clear definition of the stakeholders’ needs and constraints that will support system requirements development in the next step. Interviews, workshops, and surveys are some of the techniques that are used to perform this activity. The ConOps is a great tool for defining needs since it forces the stakeholders to think about the way the system will behave and how it will interact with users and other systems. The operational scenarios in the ConOps are among the best tools for discovering needs. The list of needs that is generated should be prioritized by the stakeholders. Once they start to compare and rank the needs, they will discover that some of their “needs” are really “wants” or “nice-to-haves”.

- **Create a System Validation Plan** – The initial performance measures that are identified in the ConOps provide a foundation for the System Validation Plan. While expectations
for the system will change over time, the performance measures outlined in the ConOps force early consideration and agreement of how system performance and project success will be measured. Examples of performance measures include travel time, incident duration, and level of service. You should define a set of performance measures that will assess the effectiveness of the system you are implementing.

A System Validation Plan is prepared that defines the consensus validation approach and performance measures. As with the ConOps, all affected stakeholder organizations should formally approve the System Validation Plan at this early stage so that downstream, all will agree on when they can “declare victory” that the new system is the right system. The plan will be finalized during system validation (see Section 4.9.2).

4.3.3 Output

The ConOps should be an approachable document that is relevant to all project stakeholders, including system operators, maintainers, developers, owners/decision makers, and other transportation professionals. The art of creating a good ConOps lies in using natural language and supporting graphics so that it is accessible to all while being technically precise enough to provide a traceable foundation for the requirements document and the System Validation Plan.

The ConOps is not a requirements document that lists the detailed, testable requirements for the system, nor is it a design document that specifies the technical design or technologies to be used. Resist the temptation to predetermine the solution in the ConOps – you should not unnecessarily preclude viable options at this early step. You also want to “keep it simple” and refrain from using formalized, highly structured English that is more suitable for the requirements and design specifications that follow.

Done right, the ConOps will be a living document that can be revised and amended so that it continues to reflect how the system is really operated. Later in the life cycle, an up-to-date ConOps can be used to define changes and upgrades to the system.

Two different industry standards provide suggested outlines for Concepts of Operations: ANSI/AIAA-G-043-1992 and IEEE Std 1362-1998, as shown in Figure 13. Both outlines include similar content, although the structure of the IEEE outline lends itself more to incremental projects that are upgrading an existing system or capability. The ANSI/AIAA outline is focused on the system to be developed, so it may lend itself more to new system developments where there is no predecessor system. Successful ConOps have been developed using both outlines. Obtain a copy of both, and make your own choice if you need to develop a ConOps.

### ANSI/AIAA-G-043 Outline

1. Scope
2. Referenced Documents
3. User-Oriented Operational Description
4. Operational Needs
5. System Overview
6. Operational Environment
7. Support Environment
8. Operational Scenarios

### IEEE 1362 Outline

1. Scope
2. Referenced Documents
3. The Current System or Situation
4. Justification for and Nature of Changes
5. Concepts for the Proposed System
6. Operational Scenarios
7. Summary of Impacts
8. Analysis of the Proposed System

Figure 13: Industry-Standard Outlines for Concept of Operations

Graphics should be used to highlight key points in the ConOps. At a minimum, a system diagram that identifies the key elements and interfaces and clearly defines the scope of the
project should be included. Tables and graphics can also be a very effective way to show key goals and objectives, operational scenarios, etc.

The Rule/Policy requires identification of participating agency roles and responsibilities as part of the systems engineering analysis for ITS projects. It also requires that the procedures and resources necessary for operations and management of the system be defined. These elements are initially defined and documented for the project as part of the ConOps. In the ANSI/AIAA standard outline, most of these elements fit under Chapter 3 (User-Oriented Operational Description). In the IEEE outline, the current system information is included in Chapter 3 and the proposed system information is in Chapter 5.

The System Validation Plan that is created during this step should describe how the final system will be measured to determine whether or not it meets the original intent of the stakeholders as described in the ConOps. (For further details and examples, see Section 4.9.)

4.3.4 Examples

Many Concepts of Operations have been generated for all types of ITS projects in the last five years. Excerpts from a few examples are included here to show some of the ways that key elements of the ConOps have been documented for ITS projects following the sequence from the ANSI/AIAA outline.

User-Oriented Operational Description (Roles and Responsibilities)

Typically, roles and responsibilities are documented as a list or in tabular form. Table 5 is an excerpt of a table from the California Advanced Transportation Management System (CATMS) ConOps that is structured to show shared responsibilities and to highlight coordination points between the different system stakeholders. This early documentation of “who does what” grabs the stakeholders’ attention and supports development of system requirements and operational agreements and procedures in future steps.

Table 5: Roles and Responsibilities (Excerpt from CATMS Concept of Operations)

<table>
<thead>
<tr>
<th>Position</th>
<th>TMC Manager</th>
<th>TMC Operator</th>
<th>Maintenance Dispatch</th>
<th>IT</th>
<th>HQ Engineer</th>
<th>District Deputy of Operations</th>
<th>Program Manager</th>
<th>Director</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contacting Executives</td>
<td>L</td>
<td>S</td>
<td></td>
<td></td>
<td>L</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>After incident briefing and analysis</td>
<td>L</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Signal timing adjustments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field data detection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>Weather monitoring</td>
<td>L</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road condition monitoring and communication</td>
<td>S</td>
<td>L</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special event traffic monitoring</td>
<td>S</td>
<td>L</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workzone lane closure logging</td>
<td>S</td>
<td>L</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitor workzone duration and congestion</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incident response management</td>
<td>L</td>
<td>L</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>News monitoring</td>
<td>S</td>
<td>L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
System Overview

The system overview is typically supported by one or more diagrams that show the scope, major elements, and interrelationships of the system. Many types of diagrams can be used, from simple block diagrams to executive-level graphics-rich diagrams. Figure 14 is an example of a high-level graphic that includes basic process flow information, roles and responsibilities, and interfaces, providing an “at a glance” overview of the major facets of the system.

Figure 14: Example of System Overview Graphic  (from Communicating with the Public Using ATIS During Disasters Concept of Operations)

Operational Scenarios

In operational scenarios, the ConOps takes the perspective of each of the stakeholders as different scenarios unfold that illustrate major system capabilities and stakeholder interactions under normal and stressed (e.g., failure mode) circumstances. The stakeholders walk through the scenario and document what the agencies and system would do at each step.

Figure 15 shows an example of a scenario that includes some realistic detail that help stakeholders immerse themselves in the scenario and visualize system operation. This is one of five scenarios that were developed for the City of Lincoln StarTRAN AVL system to show the major system capabilities and the interactions between the AVL system and its users and other interfacing systems.
Marcel, a StarTran bus operator, usually begins his work shift with administrative activities. After receiving supervisory direction, he boards the bus and prepares the AVL system. He begins by logging into the system.

The system then prompts Marcel for the route to be followed. He enters the planned route number, and the AVL system retrieves the appropriate route and schedule information from the AVL system server. The bus’ AVL system then asks Marcel to verify the appropriate route and schedule information were properly retrieved.

Once he provides verification, the bus’ head sign is automatically updated to reflect the appropriate route information. The fare payment schedule is automatically adjusted to reflect the verified route, modified as necessary by the system clock to reflect any applicable time-differential rates.

The system then loads the appropriate bus stop announcements for the chosen route. These prerecorded announcements are consistent regardless whether Marcel or another bus operator is driving the route, and have been verified as ADA compliant. These announcements are then broadcast at the appropriate bus stop throughout the route.

Figure 15: Operational Scenario Description

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11From “StarTran Automated Vehicle Location System Concept of Operations”, StarTran and City of Lincoln, NE.
### 4.4 System Requirements

**In this step:** The stakeholder needs identified in the Concept of Operations are reviewed, analyzed, and transformed into verifiable requirements that define *what* the system will do but not *how* the system will do it. Working closely with stakeholders, the requirements are elicited, analyzed, validated, documented, and baselined.

<table>
<thead>
<tr>
<th>OBJECTIVES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Develop a validated set of system requirements that meet the stakeholders’ needs</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INPUT Sources of Information</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Concept of Operations (stakeholder needs)</td>
<td></td>
</tr>
<tr>
<td>▪ Functional requirements, interfaces, and applicable ITS standards from the regional ITS architecture</td>
<td></td>
</tr>
<tr>
<td>▪ Applicable statutes, regulations, and policies</td>
<td></td>
</tr>
<tr>
<td>▪ Constraints (required legacy system interfaces, hardware/software platform, etc.)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PROCESS Key Activities</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Elicit requirements</td>
<td></td>
</tr>
<tr>
<td>▪ Analyze requirements</td>
<td></td>
</tr>
<tr>
<td>▪ Document requirements</td>
<td></td>
</tr>
<tr>
<td>▪ Validate requirements</td>
<td></td>
</tr>
<tr>
<td>▪ Manage requirements</td>
<td></td>
</tr>
<tr>
<td>▪ Create a System Verification Plan</td>
<td></td>
</tr>
<tr>
<td>▪ Create a System Acceptance Plan</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OUTPUT Process Results</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ System Requirements document</td>
<td></td>
</tr>
<tr>
<td>▪ System Verification Plan</td>
<td></td>
</tr>
<tr>
<td>▪ Traceability Matrix</td>
<td></td>
</tr>
<tr>
<td>▪ System Acceptance Plan</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REVIEW Proceed only if you have:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Received approval on the System Requirements document from each stakeholder organization, including those that will deploy, test, install, operate, and maintain the new system</td>
<td></td>
</tr>
<tr>
<td>▪ Received approval on the System Verification Plan from the project sponsor, the test team, and other stakeholder organizations</td>
<td></td>
</tr>
<tr>
<td>▪ Received approval on the System Acceptance Plan from the project sponsor, the Operations &amp; Maintenance (O&amp;M) team, and other stakeholder organizations</td>
<td></td>
</tr>
</tbody>
</table>
4.4.1 Overview

One of the most important attributes of a successful project is a clear statement of requirements that meet the stakeholders’ needs. Unfortunately, creating a clear statement of requirements is often much easier said than done. The initial list of stakeholder needs that are collected will normally be a jumble of requirements, wish lists, technology preferences, and other disconnected thoughts and ideas. A lot of analysis must be performed to develop a good set of requirements from this initial list.

EIA-632\textsuperscript{12} defines requirement as “something that governs what, how well, and under what conditions a product will achieve a given purpose.” This is a good definition because it touches on the different types of requirements that must be defined for a project. Functional requirements define “what” the system must do, performance requirements define “how well” the system must perform its functions, and a variety of other requirements define “under what conditions” the system must operate. Requirements engineering covers all of the activities needed to define and manage requirements that are shown in Figure 16.

Specify What, Not How. Be sure to keep the definition of a requirement in mind as you develop your system requirements. Many requirements documents contain statements that are not requirements. One of the most common pitfalls is to jump to a design solution and then write “requirements” that define how the system will accomplish its functions. Specify what the system will do in the system requirements, and save how the system will do it for the system design step.

It is important to involve stakeholders in requirements development. Stakeholders may not have experience in writing requirements statements, but they are the foremost experts concerning their own requirements. The project requirements ultimately are the primary formal communication from the system stakeholders to the system developer. The project will be successful only if the requirements adequately represent stakeholders’ needs and are written so they will be interpreted correctly by the developer.

In the effort to get stakeholders involved, make sure you don’t sour them on the project by making unreasonable demands on their time or putting them in situations where they can’t contribute. Many nontechnical users have been subjected to stacks of detailed technical outputs that they can’t productively review. Sooner or later, the user will wave the white flag in this situation and become unresponsive. You must (1) pick your stakeholders carefully and (2) make participation as focused and productive as possible.

\textsuperscript{12}EIA-632 is the Electronics Industry Association Standard “Processes for Engineering a System”.

Figure 16: Requirements Engineering Activities
The Requirements step is an important one that you shouldn’t skimp on. Every ITS project should have a documented set of requirements that are approved and baselined. Of course, this doesn’t mean that a new requirements specification must be written from scratch for every project. Projects that enhance or extend an existing system should start with the existing system requirements. This doesn’t have to be a particularly large document for smaller ITS projects. The system requirements specification for a recent website development project was less than 20 pages.

4.4.2 Key Activities

There isn’t one “right” approach for requirements development. Different organizations develop requirements in different ways. Even in the same organization, the requirements development process for a small ITS project can be much less formal than the process for the largest, most complex ITS projects. The differences are primarily in the details and in the level of formality. All requirements development processes should involve elicitation, analysis, documentation, validation, and management activities. Note that each of these activities is highly iterative. In the course of a day, a systems engineer may do a bit of each of the activities as a new requirement is identified, refined, and documented.

- **Elicit requirements** – Building on the stakeholders’ needs and other inputs, such as the functional requirements from the regional ITS architecture and any relevant statutes, regulations, or policies, define a strawman set of system requirements and review and expand on them, working closely with the project stakeholders. There are many different elicitation techniques that can be used, including interviews, scenarios (see discussion under Concept of Operations in Section 4.3), prototypes, facilitated meetings, surveys, and observations. These techniques can be used in combination to discover the stakeholders’ requirements.

  *Elicit* and * elicitation* are words you may not run into every day. *Elicit* means to draw forth or to evoke a response. This is the perfect word to use in this case because you will have to do some work to draw out the requirements from the stakeholders and any existing documentation. More work is implied by “elicit requirements” than if we said “collect requirements” or even “identify requirements”, and this is intended.

  Make sure that you have the right stakeholders involved. This means not only the right organizations but also the right individuals within them. For example, it isn’t enough to engage someone from the maintenance organization – it should be an electrical maintenance person who has experience with ITS equipment maintenance for ITS projects. Furthermore, as we move through the steps in the process and the products become more technical, different stakeholders may be involved. Managers may be more involved in the Concept of Operations, while technical staff will be more involved in review of the system requirements and high-level design. Finding individuals with the right combination of knowledge of current operations, vision of the future system, and time to invest in supporting requirements development is one of the key early challenges in any requirements development effort.

There are many techniques for working with stakeholders to get to the fundamental requirements of the system. The Florida SEMP\(^{13}\) highlights one of the best and simplest techniques – the “Five Whys” – that was popularized by Toyota in the 1970s. Using the Five Whys technique, you look at an initially stated need and ask “Why?” repeatedly, not

unlike a curious four-year-old, until you find the real underlying requirements. The dialog in Table 6 is an example that is based on an actual conversation.

Table 6: The “Five Whys” Technique in Action

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Systems Engineer</th>
</tr>
</thead>
<tbody>
<tr>
<td>I need irrigation channels on my keyboard.</td>
<td>Why?</td>
</tr>
<tr>
<td>I occasionally spill coffee on the keyboard.</td>
<td>Why?</td>
</tr>
<tr>
<td>I need to have three or four manuals open to operate the system and the coffee just gets knocked over.</td>
<td>Why do you need to have three or four manuals open?</td>
</tr>
<tr>
<td>…</td>
<td>…</td>
</tr>
</tbody>
</table>

The dialog continues as the systems engineer discovers several different underlying needs that will drive environmental requirements, human factors/workspace requirements, and user interface requirements, all by pursuing the initial stated need for “irrigation channels”.

Of course, you sometimes need to direct the conversation by asking more than “why” to use this technique effectively. In the example, the conversation could easily have veered off to a discussion of the user’s love for Starbucks coffee. Five iterations is a good rule of thumb, but it may take fewer or more iterations – the idea is to be persistent until you get to the core issues. Note also that the dialog can be internal – the stakeholder could have sat down and asked herself “Why”, using the same technique to get at her underlying needs.

As you gather the requirements, be sure to look beyond the operational requirements for the system and cover the complete life cycle (system development, deployment, training, transition, operations and maintenance, upgrades, and retirement) as well as requirements such as security and safety. More than one ITS project has failed because the security requirements of public safety stakeholders were not captured and reflected in the ITS project requirements. A good system requirements template can be used as a checklist to help ensure that all types of requirements are considered.

The best way to start writing requirements is to use just two words: a verb and a noun. For example, the user requirement “monitor road weather conditions” would yield system requirements such as “shall detect ice”, “shall monitor wind speed”, and “shall monitor pavement temperature”. Performance requirements would define the different kinds of ice conditions and the range of wind speeds and pavement temperatures.

- Analyze requirements – The requirements are analyzed in detail, and the stakeholders negotiate to prioritize them. This is where the requirements are cleaned up: conflicts are resolved, gaps are identified and addressed, ambiguity and redundancy are removed, and the requirements are organized and decomposed into more detailed requirements. Several levels of requirements are developed, providing sufficient granularity so that they can be allocated to individual subsystems and components in the next step, high-level design.

Requirements are normally defined in a requirements hierarchy in which the highest-level “parent” requirements are supported by more detailed “child” requirements. A hierarchy allows you to start with high-level requirements and work your way down to the details. The highest-level requirements should trace to stakeholder needs in the Concept of Operations. A hierarchy is a useful organizational structure that makes it easier to write and review requirements and to manage the requirements development activity. An example of a requirements hierarchy is given in Figure 17.
Figure 17: Example of Hierarchy of High-Level and Detailed Requirements

For larger systems, it can be very difficult to “get your arms around” all of the requirements. Requirements modeling tools provide a graphic way to define requirements so that they are easier to understand and analyze. These tools are particularly useful for more complex ITS projects. There are numerous requirements modeling tools and techniques available that can help you model the system as part of the analysis process. INCOSE maintains a data repository of available modeling tools that is available on its website14.

A model is a representation of something else. There are physical models, like the scale model of a train, and more abstract models, like an architectural plan for a new building. Many different models of the system to be built can be created and used as part of the systems engineering process. During requirements analysis, logical models are used that describe what the system will do. Later, during system design, physical models are created that show how the system will be implemented.

Requirements modeling is an iterative process. Draft models can be developed early in the process based on the Concept of Operations and the regional ITS architecture. These models are refined as they are used to support requirements elicitation and walkthroughs, keeping bounds on the system and reducing requirements creep.

• Document requirements – The requirements are documented in a well-organized, approachable fashion so that the stakeholders and system development team can all easily understand and review them. Typically, a combination of plain language and diagrams are used to define the requirements.

The requirements documentation should include more than requirements. There are many different attributes that should be tracked for each requirement. A rich set of attributes is particularly important for large, complex projects. If you are developing such a project, consider specifying the following for each requirement: requirement number, source, author, creation date, change history, verification method, priority, and status. The historical and change-tracking attributes are particularly important since they allow management to measure and track requirements stability.

Traceability is another important aspect of requirements documentation. Each requirement should trace to a higher-level requirement, a stakeholder need, or other governing rules, standards, or constraints from which the requirement is derived. As the system is developed, each requirement will also be traced to the test case that will verify it, to more detailed “child” requirements that may be derived from it, and to design elements that will help to implement it. Establish and populate the Traceability Matrix at this stage, and continue to populate it during development. The Traceability Matrix is a

vital document that is maintained to the end of project development, allowing traceability from user needs to the system components, verification, and validation.

- **Validate requirements** – The documented requirements are carefully checked for consistency, accuracy, and completeness. This is a critical step that is intended to identify requirement defects as early in the process as possible, when correcting them is most economical. To support validation, requirements walkthroughs are held to review the requirements in a systematic way with the project stakeholders and project team.

You will see “validation” used in a few different contexts in systems engineering. Here in requirements validation, you make sure that the requirements are correct and complete. Later, in system validation (discussed in Section 4.9), you make sure that you have built the right system. In fact, the requirements validation that is performed here will ultimately help to make sure that the system validation is successful in the end.

A walkthrough is a technique in which a review team steps through a deliverable (e.g., requirements, design, or code) looking for problems. A walkthrough should be relatively informal and “blame free” to maximize the number of problems that are identified. A requirements walkthrough should be attended by the people that have a vested interest in the requirements. For a large project, this might include the requirements author, customer, user representative(s), implementers, and testers.

Table 7 identifies an oft-repeated list of attributes of good requirements. As part of the validation process, you do your best to make sure that the requirements have all of these desired attributes. Unfortunately, computers can do only a fraction of this validation and people have to do the rest. Techniques for validating a requirement against each of these quality attributes are also shown in Table 7. An attribute list like this can be converted into a checklist that prompts reviewers to ask themselves the right questions as they are reviewing the requirements.

### Table 7: Validating Quality Attributes of Good Requirements

<table>
<thead>
<tr>
<th>Quality Attribute</th>
<th>Validate by:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Necessary</td>
<td>Make sure that each requirement traces to either a stakeholder need in the ConOps or a parent requirement. A computer can check that the traceability is complete, but people have to verify that the identified traces are valid.</td>
</tr>
<tr>
<td>Clear</td>
<td>Some requirements management tools can help with this by looking for red-flag words and constructs in the requirements (e.g., “user friendly”, “optimum”, “real-time”, pronouns, and complex sentences). Most of this aspect of validation relies on walkthroughs and other reviews to make sure the requirements aren’t subject to different interpretations. The main culprit here is ambiguity in the English language.</td>
</tr>
<tr>
<td>Complete</td>
<td>Does every stakeholder or organizational need in the ConOps trace to at least one requirement? If you implement all of the requirements that trace to the need, will the need be fully met? A computer can answer the first question, but only stakeholder(s) can answer the second.</td>
</tr>
<tr>
<td>Correct</td>
<td>In general, it takes a walkthrough to verify that the requirements accurately describe the functionality and performance that must be delivered. The stakeholders must validate that the highest-level system requirements are correct. Traceability can assist in determining the correctness of lower-level requirements. If a child requirement is in conflict with a parent requirement, then either the parent or the child</td>
</tr>
</tbody>
</table>
### Quality Attribute | Validate by:
--- | ---
Feasible | Again, this must be determined by review and analysis of the requirements. A computer can help with the analysis and possibly even flag words like “instant” or “instantaneous” that may be found in infeasible requirements, but a person ultimately makes the judgment of whether the requirements are feasible. In this case, it is the developer who can provide a reality check and identify requirements that may be technically infeasible or key cost drivers early in the process. Since system performance is dependent on system design and technology choices, requirements feasibility will continue to be monitored and addressed as the system design is developed.
Verifiable | Does the requirement have a verification method assigned? (This is something a computer can check.) Is the requirement really stated in a way that is verifiable? (This much more difficult check can only be performed by people.) For example, ambiguous requirements are not verifiable.

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- **Manage requirements** – Processes and tools are established to manage the requirements and associated information that is collected, track changes to the requirements, and provide facilities that support traceability, requirements retrieval and reporting, etc. (See Section 5.4 for more information on configuration management techniques that should be used on the requirements baseline.)

Every ITS project should have a tool that helps to manage the requirements baseline. More complex ITS projects will benefit from a tool specifically for requirements management such as DOORS or Requisite-Pro. A professional requirements management tool is expensive, but it includes a long list of capabilities including change management, requirements attributes storage and reporting, impact analysis, requirements status tracking, requirements validation tools, access control, and more.

Like the other requirements engineering activities, the requirements management capabilities should be scaled based on the complexity and size of the ITS project. Requirements for smaller ITS projects can be managed easily and effectively by a single engineer using a general purpose tool like Microsoft Access or Excel.

- **Create a System Verification Plan** – As the requirements are documented, a plan for verifying the system based on the requirements is defined. This is extremely important because only verifiable requirements should find their way into the system requirements document. A verification method is identified for every requirement – normally, by one of four ways: Test, Demonstration, Inspection, or Analysis. The purpose of this early assignment of a method, long before the requirements will actually be verified, is to make sure that the requirements author thinks about how the requirement will be verified from the very start. (See Section 4.7 for more information on System Verification.)

- **Create a System Acceptance Plan** – A plan should be created that describes the functionality the new system must successfully display prior to acceptance by the customer; consensus by all parties on the contents of this plan should be reached early in the life cycle.

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15INCOSE ([www.incose.org](http://www.incose.org)) has a comprehensive list of requirements management tools in its tools database.
4.4.3 Outputs

No matter how you developed your requirements, you must document them in some consistent, accessible, and reviewable way. The requirements development process may result in several different levels of requirements over several steps in the “V” – stakeholder requirements, system requirements, subsystem requirements, etc. – that may be documented in several different outputs. For example, stakeholder requirements might be documented in a series of Use Cases; system requirements, in a System Requirements Specification; and subsystem requirements, in subsystem specifications. All of these requirements should be compiled in a single repository that can be used to manage and publish the requirements specifications at each stage of the project.

It is much easier to use a standard template for the requirements specifications than it is to come up with your own, and numerous standard templates are available. If your organization does not have a standard requirements template, you can start with a standard template like the one contained in IEEE Standard 830 (for software requirements specifications) or IEEE Standard 1233 (for system requirements specifications). Starting with a template saves time and ensures that the requirements specification is complete. Of course, the template can be modified as necessary to meet the needs of the project.

The system requirements specification should fully specify the system to be developed and should include the following information:

- System boundary with interfacing systems clearly identified
- General system description, including capabilities, modes, and users, as applicable
- External interface requirements for interfacing systems and people
- Functional requirements and associated performance requirements
- Environmental requirements
- Life-cycle process requirements supporting development, qualification (e.g., test, verification, validation, and acceptance), production, deployment, transition, operations and maintenance, change and upgrade, and retirement/replacement, as applicable
- Reliability and availability
- Expandability
- Staffing, human factors, safety, and security requirements; and
- Physical constraints (such as weight and form factors).

As you read through this list, you may recognize that some of this information has already been collected and documented in previous steps, and there is no need to recreate it here. Refer back to the Concept of Operations that already contains a description of the system boundary, the system itself, and other items in this list.

A System Verification Plan, describing the approach for verifying each and every system requirement, and a System Acceptance Plan, describing the capabilities that must function successfully for customer acceptance, should be created, reviewed, and approved.
### 4.4.4 Examples

#### Stakeholder Requirements

The Oregon DOT TripCheck project developed a User Functional Requirements Specification, which lists the user requirements for the redesigned TripCheck website. The excerpt from this document in Table 8 shows several user requirements for the website autorouting function. As shown, every requirement is prioritized on a scale from 1 (“must have”) to 4 (“don’t implement”) and is related to different types of end users – Commuters (C), Inter-City Travelers (ICT), Tourist Travelers (TT), ADA Travelers (ADA), and Commercial Truckers (CT). These prioritized user requirements were used by the contractor to support Use Case modeling and to define system requirements.

#### Table 8: ODOT TripCheck User Requirements (Excerpt)

<table>
<thead>
<tr>
<th>REQ ID</th>
<th>ODOT PRIORITY</th>
<th>REQUIREMENT</th>
<th>AUDIENCE SEGMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR001</td>
<td>2</td>
<td>The system should allow the user to enter a multi-point route using a combination of the criteria specified in MP004c-f and h.</td>
<td>X</td>
</tr>
<tr>
<td>RR0011</td>
<td>1</td>
<td>The system shall allow the user to select destination points by clicking on the map.</td>
<td>X</td>
</tr>
<tr>
<td>RR002a</td>
<td>2</td>
<td>- starting date AND/OR ending date if only one date is specified, the system calculates the other.</td>
<td></td>
</tr>
<tr>
<td>RR002b</td>
<td>2</td>
<td>- starting time/ending time if only one time is specified, the system calculates the other.</td>
<td></td>
</tr>
<tr>
<td>RR002c</td>
<td>2</td>
<td>- month of travel (instead of start/end)</td>
<td></td>
</tr>
<tr>
<td>RR002d</td>
<td>4</td>
<td>- quickest route (by time)</td>
<td></td>
</tr>
<tr>
<td>RR002e</td>
<td>1</td>
<td>- shortest route (by miles)</td>
<td>X</td>
</tr>
<tr>
<td>RR002f</td>
<td>2</td>
<td>- most scenic route (based on scenic byways within a user-specified mile radius of the direct (shortest) route</td>
<td></td>
</tr>
<tr>
<td>RR002g</td>
<td>3</td>
<td>- routes most recommended by others</td>
<td></td>
</tr>
</tbody>
</table>

Note that stakeholder requirements that are collected through the requirements elicitation process are likely to have a few imperfections. The key is to document the stakeholder requirements, make them as clear and succinct as possible, prioritize them, and then use them to develop more formally stated system requirements.

#### System Requirements

The Maryland CHART II system is a statewide traffic management system that has been operational since 2001. The CHART program maintains a website that provides all of the CHART documentation at [http://www.chart.state.md.us](http://www.chart.state.md.us), including a comprehensive system
requirements document. A few of the system requirements for the equipment inventory and report generation functions are shown in Table 9.

Table 9: CHART II System Requirements (Excerpt)

<table>
<thead>
<tr>
<th>3.1.3 Equipment Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>The equipment inventory is a list of SHA equipment used in connection with CHART response to incidents. The system provides functions to maintain the inventory, equipment status, and to generate alerts for delinquent equipment.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3.1.3.1 The system shall provide the capability to maintain the equipment inventory.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.3.1.1 The system shall support the addition of new equipment entries to the inventory.</td>
</tr>
<tr>
<td>3.1.3.1.2 The system shall support the modification of existing equipment inventory entries.</td>
</tr>
<tr>
<td>3.1.3.1.3 The system shall support the deletion of equipment inventory entries.</td>
</tr>
<tr>
<td>3.1.3.1.4 The system shall support the allocation of equipment to events.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3.1.4 Report Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>This section lists requirements for the generation of reports from the CHART system and archive data.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3.1.4.1 The system shall provide the capability to generate reports from online and archived data.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.4.2 The system shall support the generation of operational reports.</td>
</tr>
<tr>
<td>3.1.4.2.1 The system shall support the generation of a Center Situation report.</td>
</tr>
<tr>
<td>3.1.4.2.2 The system shall support the generation of a Disable Vehicle event report.</td>
</tr>
<tr>
<td>3.1.4.2.3 The system shall support the generation of an Incident event report.</td>
</tr>
<tr>
<td>3.1.4.2.4 The system shall support the generation of traffic volume reports.</td>
</tr>
</tbody>
</table>

Traceability Matrix

Table 10 is a typical traceability matrix that would be maintained and populated throughout the project development process. The matrix may be maintained directly in a database or spreadsheet for small projects or generated and maintained with a requirements management tool for more complex projects. Using either approach, the matrix provides backwards and forwards traceability between stakeholder needs (and other potential requirements sources), system requirements, design, implementation, and verification test cases. As shown, only the unique identifiers (e.g., UN1.1) are actually included in the traceability matrix so you don’t have to keep many instances of the actual text up-to-date. Note also that the design and implementation columns would not actually be completed until later in the process.

Table 10: Sample Traceability Matrix

<table>
<thead>
<tr>
<th>Requirement Source</th>
<th>System Requirement</th>
<th>High-Level Design Component</th>
<th>Code Unit</th>
<th>Test Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>UN1.1</td>
<td>R00220</td>
<td>7.2.3</td>
<td>SystemMonitor</td>
<td>UT 4.2</td>
</tr>
<tr>
<td></td>
<td>R00330</td>
<td>7.3.1</td>
<td>CalcVolume</td>
<td>UT 5.5</td>
</tr>
<tr>
<td></td>
<td>R00331</td>
<td>7.3.1</td>
<td>CalcCount</td>
<td></td>
</tr>
</tbody>
</table>
### 4.5 System Design

**In this step:** A system design is created based on the system requirements including a high-level design that defines the overall framework for the system. Subsystems of the system are identified and decomposed further into components. Requirements are allocated to the system components, and interfaces are specified in detail. Detailed specifications are created for the hardware and software components to be developed, and final product selections are made for off-the-shelf components.

#### OBJECTIVES
- Produce a high-level design that meets the system requirements and defines key interfaces, and that facilitates development, integration, and future maintenance and upgrades
- Develop detailed design specifications that support hardware and software development and procurement of off-the-shelf equipment

#### INPUT: Sources of Information
- Concept of Operations
- System Requirements document
- Off-the-shelf products
- Existing system design documentation
- ITS standards
- Other industry standards

#### PROCESS: Key Activities
- Evaluate off-the-shelf components
- Develop and evaluate alternative high-level designs
- Analyze and allocate requirements
- Document interfaces and identify standards
- Create Integration Plan, Subsystem Verification Plans, and Subsystem Acceptance Plans
- Develop detailed component-level design specifications

#### OUTPUT: Process Results
- Off-the-shelf evaluation and alternatives summary reports
- High-level (architectural) design
- Detailed design specifications for hardware/software
- Integration Plans, Subsystem Verification Plans, Subsystem Acceptance Plans, and Unit/Device Test Plans

#### REVIEW: Proceed only if you have:
- Approved high-level design for the project
- Defined all system interfaces
- Traced the system design specifications to the requirements
- Approved detailed specifications for all hardware/software components
4.5.1 Overview

In the systems engineering approach, we define the problem before we define the solution. The previous steps in the “V” have all focused primarily on defining the problem to be solved. The system design step is the first step where we focus on the solution. This is an important transitional step that links the system requirements that were defined in the previous step with system implementation that will be performed in the next step, as shown in Figure 18.

There are two levels of design that should be included in your project design activities:

**High-level design** is commonly referred to as architectural design in most systems engineering handbooks and process standards. Architectural design is used because an overall structure for the project is defined in this step. IEEE 610 defines architectural design as “the process of defining a collection of hardware and software components and their interfaces to establish the framework for the development of a computer system”. Of course, ITS projects may include several computer systems, a communications network, distributed devices, facilities, and people. High-level design defines a framework for all of these project components.

**Detailed design** is the complete specification of the software, hardware, and communications components, defining how the components will be developed to meet the system requirements. The software specifications are described in enough detail that the software team can write the individual software modules. The hardware specifications are detailed enough that the hardware components can be fabricated or purchased.

Many consider design to be the most creative part of project development. Two different designs might both meet the system requirements, but one could be far superior in how efficiently it can be developed, integrated, maintained, and upgraded over time. Perhaps the most significant contributor to a successful design is previous design experience with similar systems. The latest car designs all build on 100 years of accumulated automotive design experience. Similarly, the design of a new transportation management system should build on existing successful transportation management system designs. In both cases, the system designer builds on knowledge of what worked before and, perhaps even more importantly, what did not.

It is extremely rare to find an ITS system that is truly “unprecedented”, so many if not most system designs should be able to build on existing design information. This is particularly true for projects that are extending an existing system that already includes a well-documented design. In this case, the high-level design will change only to the degree that new functionality or interfaces are added. Similarly, much of the detailed design can be reused for projects that extend the coverage of an existing system.

---

16IEEE 610 is the IEEE Standard Computer Dictionary.
4.5.2 Key Activities

System design is a cooperative effort that is performed by systems engineers and the implementation experts who will actually build the system. The process works best when there is a close working relationship among the customer, the systems engineers (e.g., a consultant or in-house systems engineering staff), and the implementation team (e.g., a contractor or in-house team).

High-Level Design

High-level design is normally led by systems engineers with participation from the implementation experts to ensure that the design is implementable. Typical activities of high-level design are shown in Figure 19. Each of the activities are actually performed iteratively as high-level design alternatives are defined and evaluated.

- **Evaluate off-the-shelf components** – One key aspect of high-level design is the identification of components that will be purchased, reused, or developed from scratch. The project may be required to use off-the-shelf hardware or software, or this may simply be the preferred solution. Specific design constraints may also require that a particular product be used. For example, a municipality that is expanding a signal control system that already includes 300 Type 170 controllers may constrain the design of the expansion to use the same controllers to facilitate operation and maintenance of the overall system. State DOTs and other large agencies often publish approved products lists that identify ITS-related products that meet agency specifications.

When off-the-shelf components will be used, the high-level design must be consistent with the capabilities of the target products. The designer should have an eye on the available products as the high-level design is produced to avoid specifying a design that can be supported only by a custom solution. A particular product should not be specified in the high-level design unless it is truly required. When possible, the high-level design should be vendor and technology independent so that new products and technologies can be inserted over time.

You should give off-the-shelf hardware and software serious consideration and use it where it makes sense. The potential benefits of off-the-shelf solutions – reduced acquisition time and cost, and increased reliability – should be weighed against the requirements that may not be satisfied by the off-the-shelf solution and potential loss of flexibility. If you have requirements that preclude off-the-shelf solutions, determine how important they are and what their real cost will be. This make/buy evaluation should be documented in a summary report that considers the costs and benefits of off-the-shelf and custom solution alternatives over the system life cycle. This report should be a key deliverable of the project.

Also recognize that there is a large grey area between off-the-shelf and custom software for ITS applications. Every qualified software developer starts with an established code base when creating the next “custom solution”, accruing some of the benefits of off-the-
shelf solutions. Many vendors of off-the-shelf solutions offer customization services, further blurring the distinction between off-the-shelf and custom software.

The FHWA report *The Road to Successful ITS Software Acquisition* includes a good discussion of software make/buy decision factors and a lot of other good information on software acquisition for ITS. The executive summary for the report is available at [www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/36s01!.pdf](http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/36s01!.pdf).

### Develop and evaluate high-level design alternatives

- The system is partitioned into subsystems, and the subsystems are in turn partitioned into smaller assemblies. The process continues until system components – the elemental hardware and software configuration items – are identified. Figure 20 shows a partial decomposition of an electronic toll collection system that identifies all of the major subsystems and the components for the Video Enforcement subsystem.

![Diagram of Electronic Toll Collection Subsystems and Components](http://ops.fhwa.dot.gov/publications/seitsguide/seguide.pdf)

There are many different ways that a system can be partitioned into subsystems and components. In this Electronic Toll Collection example, we might consider whether the Clearinghouse Processing subsystem should be handled by a single centralized facility or distributed to several regional facilities. As another example, vehicle detectors could be included in the Video Enforcement subsystem or in the Tag Reader subsystem, or both.

Even a relatively simple traffic signal system has high-level design choices. For example, a traffic signal system high-level design can be two-level (central computer and local controllers), three-level (central computer, field masters, and local controllers), or a hybrid design that could support either two or three levels. High-level design alternatives like these can have a significant impact on the performance, reliability, and life-cycle costs of the system. Alternative high-level designs should be developed and compared with respect to defined selection criteria to identify the superior design.

The selection criteria that are used to compare the high-level design alternatives include consistency with existing physical and institutional boundaries; ease of development, integration, and upgrading; and management visibility and oversight requirements. One of the most important factors is to keep the interfaces as simple, standard, and foolproof as possible. The selection criteria should be documented along with the analysis that identifies the superior high-level design alternative that will be used. If there are several viable alternatives, they should be reviewed by the project sponsor and other stakeholders.

---

**Figure 20: Electronic Toll Collection Subsystems and Components (Excerpt)**

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The Rule/Policy requires the systems engineering analysis for ITS projects to include an analysis of alternative system configurations.

- **Analyze and allocate requirements** – The requirements analysis described in Section 4.4.2 continues as the requirements are decomposed until there is enough granularity to allocate requirements to the system components identified in the high-level design.

  The detailed functional requirements and associated performance requirements are allocated to the system components. To support allocation, the relationships between the required system functions are analyzed in detail. Once you understand the relationships between functions, you can make sure that functions that have a lot of complex and/or time-constrained interactions are allocated to the same component as much as possible. Through this process, each component is made as independent of the other components as possible.

  You would not want to develop a high-level design and requirements allocation for a complex ITS project without software tools. Fortunately, there are many good tools that support both requirements analysis and architectural design. The INCOSE tools database, available to nonmembers free of charge at [www.incose.org](http://www.incose.org), includes a broad range of systems engineering tools and a detailed survey of tools that support requirements management and system architecture.

- **Document the interfaces and identify standards** – Interfaces should be identified early, fully documented, and then managed throughout the project development. Interface specifications should be developed for external interfaces (i.e., interfaces between the current project and external systems) and internal interfaces (i.e., interfaces between project components). Interfaces between systems that are owned and operated by different agencies may require additional lead time to negotiate interface agreements.

  This is the place to identify ITS standards and any other industry standards that will be used in detail. There are a variety of standards that should be considered at this point. Take a look at all interfaces, both external and internal. Since your regional ITS architecture and/or project ITS architecture was based on the National ITS Architecture, many of the interfaces probably already have a set of ITS standards you should consider.

  You should also identify standards that are used in your region or state, and also in adjoining states if your project is a multistate deployment. A methodical assessment should be made for each interface to determine which standards are relevant, which standards should be deployed, and perhaps which standards should be phased in over time as part of a longer-range plan.

  Once you have taken a look at the relevant standards, beginning with your system’s external interfaces, document the nature of the data, formats, ranges of values, and periodicity of the information exchanged on the interface. Then proceed to each of the internal interfaces and document the same information for those.

  Agencies are encouraged to incorporate the ITS standards into new systems and upgrades of existing systems. The Rule/Policy requires the systems engineering analysis for ITS projects to include an identification of ITS standards. Consult the ITS Standards Program website at [http://www.standards.its.dot.gov/](http://www.standards.its.dot.gov/) for more information and available resources supporting standards implementation.

- **Create Integration Plan, Subsystem Verification Plans, and Subsystem Acceptance Plans** – An Integration Plan, Subsystem Verification Plans, and Subsystem Acceptance Plans should be completed parallel with the high-level design. (See Section 4.7 for more information on integration and verification planning.)
Detailed Design

Hardware and software specialists create the detailed design for each component identified in the high-level design. Systems engineers play a supporting role, providing technical oversight on an ongoing basis. As you might expect, the detailed design activity will vary for off-the-shelf and custom components, as shown in Figure 21.

- **Prototype user interface** – If a user interface is to be developed, a simple user interface prototype is an efficient way to design it.

A prototype is a quick, easy-to-build approximation of a system or part of a system. A software prototype can be used to quickly implement almost any part of a system that you want to explore, but it is used most often to make a quick approximation of a user interface for a new system.

A user interface prototype should be employed to help the user and developer visualize the interface before significant resources are invested in software development. This is one area in particular where you can expect multiple iterations as the developers incrementally create and refine the user interface design based on user feedback. (You will find that it is often easier to get users to provide feedback on a prototype than on system requirements and design specifications, which can be tedious to review.)

While the user interface prototype is included here because it is an effective way to design the user interface, prototypes may actually be generated much earlier in the process, during system requirements development. The prototype can turn the requirements statements into something tangible that users can react to and comment on.

- **Develop detailed hardware and software component design specifications** – Detailed design specifications are created for each hardware and software component to be developed. In the high-level design, each component is defined in terms of its functionality and performance, with particular focus on its interfaces to external systems and other components. The level of detail in the detailed design specifications is greater than that in the high-level design in two important respects:
  - The detailed design will often include another layer of architectural design for complex components. Figure 22 shows another layer of decomposition that might be defined for the Enforcement Software component that was identified in the high-level design example for the Electronic Toll Collection system (in Figure 20). All hardware/software units and their interfaces are defined to provide a framework for development of the component.

![Figure 22: Architectural Design within a System Component](image-url)
The detailed design specifies exactly how the component will be implemented so that it meets the requirements. For hardware, schematic drawings and parts lists are defined. For software, this includes identification of algorithms, detailed data structures, and specification of third-party software packages that will be used. In the Electronic Toll Collection example, an off-the-shelf real-time executive would be selected and the image capture and character recognition algorithms would be defined.

The detailed design of each component should be reviewed to verify that it meets the allocated requirements and is fit for the intended purpose. Periodic or as-needed reviews can be held to monitor progress and resolve any design issues. For larger projects, coordination meetings should be held to ensure that concurrent design activities are coordinated to mitigate future integration risks. At the completion of the detailed design step, a broader stakeholder meeting is held to review and approve the detailed design before the implementation team begins to build the solution.

**Select off-the-shelf (OTS) products** – One of the fundamental principles of systems engineering is to delay technology choices until you have a solid foundation for making the right choice. By waiting until this point in the process, the latest technologies and products can be selected, and these selections can be based on a thorough understanding of the requirements and the overall architecture of the system. The selections can also be made by specialists who are closest to the implementation and are therefore best equipped to make them.

There are two fundamental ways that a product can be selected, depending on your procurement requirements and selected procurement strategy:

- A trade study can be performed that compares the alternative products and selects the best product based on selection criteria that are in turn based on the specification.
- A competitive procurement can be used that allows vendors to propose products that will best meet the specification.

In either case, product selection should be driven by a good performance-based specification of the product.

Specifications can be either **performance-based** or **prescriptive**. In a performance-based specification, you specify the functionality and the performance that are required rather than what equipment to use. In a prescriptive specification, you specify exactly the equipment that you want. A performance-based specification for a dynamic message sign would include statements like “The sign shall provide a display of 3 lines of 25 characters per line.” A prescriptive specification would be “The Trantastic LED Model XYZ sign shall be used.” Performance-based specifications tend to provide the best value because they allow the contractor or vendor maximum flexibility to propose the best solution that meets your needs.

If a trade study is performed, then the functional and performance requirements that are allocated to the product should be used to define product selection criteria. An alternatives analysis document captures the alternatives that were considered and the selection criteria that were used to select the superior product. Existing trade studies, approved product lists, and other resources can be used to facilitate product selection.

The evaluation of OTS products should be reviewed to verify that the evaluation criteria were properly defined and applied fairly and that an appropriate range of products was considered.
- **Create Unit/Device Test Plans** – Test plans should be created for each hardware and software component to test all requirements identified in the HW/SW design specifications.

### 4.5.3 Outputs

#### High-Level Design

There isn’t a single “best way” to present the high-level design to stakeholders and developers since different users will have different needs and different viewpoints. Over the years, high-level designs have evolved to include several different interconnected “views” of the system. Each view focuses on a single aspect of the system, which makes the system easier to analyze and understand. The specific views that are presented will vary, but they will typically include a physical view that identifies the system components and their relationships; a functional view that describes the system’s behavior; a technical view that identifies the interfaces in detail, including the standards to be used; and an informational view that describes the information that will be managed by the system. As shown in Figure 23, these views are just different ways of looking at the same system.

![Figure 23: High-Level Design May Include Several Views](http://ops.fhwa.dot.gov/publications/seitsguide/seguide.pdf)

Other outputs of the high-level design process include Integration Plans, Subsystem Verification Plans, and Subsystem Acceptance Plans that will be used in the integration and verification of the system. (See Section 4.7 for further details.)
Detailed Design

This activity results in the design of hardware and software for all system components that will support hardware and software development and off-the-shelf product procurement. Other artifacts of the development process include unit/device verification plans. A record of the technical reviews that were conducted should also be included in the project documentation.

4.5.4 Examples

High-Level Design

The CHART II documentation includes a system architecture document that includes many different views of the CHART II system, such as entity relationship diagrams, Use Case diagrams, and network architecture diagrams. Table 11 is an excerpt from the document that shows the subsystems included in the CHART II software.

In contrast with the CHART II statewide system high-level design, many smaller ITS projects have relatively simple high-level designs, such as the system architecture for the MyBus system depicted in Figure 24. This figure identifies the subsystems and major interfaces in the MyBus system.

ITS projects that include significant user interface development should prototype the user interface to

Table 11: CHART II Software Subsystems (Excerpt)

<table>
<thead>
<tr>
<th>CI Name</th>
<th>Subsystems</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHART II</td>
<td>Alert Management</td>
</tr>
<tr>
<td></td>
<td>Audio</td>
</tr>
<tr>
<td></td>
<td>AVL</td>
</tr>
<tr>
<td></td>
<td>Camera Control</td>
</tr>
<tr>
<td></td>
<td>Communications Log Management</td>
</tr>
<tr>
<td></td>
<td>Data Export Management</td>
</tr>
<tr>
<td></td>
<td>Device Management</td>
</tr>
<tr>
<td></td>
<td>Dictionary</td>
</tr>
<tr>
<td></td>
<td>DMS Control</td>
</tr>
<tr>
<td></td>
<td>HAR Control</td>
</tr>
<tr>
<td></td>
<td>HAR Notification</td>
</tr>
<tr>
<td></td>
<td>Message Library Management</td>
</tr>
<tr>
<td></td>
<td>Notification Management</td>
</tr>
<tr>
<td></td>
<td>Plan Management</td>
</tr>
<tr>
<td></td>
<td>Resource Management</td>
</tr>
<tr>
<td></td>
<td>Schedule Management</td>
</tr>
<tr>
<td></td>
<td>SHAZAM Management</td>
</tr>
<tr>
<td></td>
<td>Signals</td>
</tr>
<tr>
<td></td>
<td>Simulation</td>
</tr>
<tr>
<td></td>
<td>System Monitor</td>
</tr>
<tr>
<td></td>
<td>Traffic Event Management</td>
</tr>
<tr>
<td></td>
<td>Traffic Sensor System Management</td>
</tr>
<tr>
<td></td>
<td>User Management</td>
</tr>
<tr>
<td></td>
<td>Utility</td>
</tr>
<tr>
<td></td>
<td>Video Monitor Management</td>
</tr>
</tbody>
</table>

Figure 24: Metro Transit MyBus System Architecture
help users visualize the software that will be developed before significant resources are committed. The objective is to develop a prototype that demonstrates the software look and feel with the least amount of work possible. The simplest prototypes are a series of static images in paper form. For example, when ODOT redesigned its TripCheck website, the implementation team developed a series of “wireframe” diagrams that showed the proposed interface design with enough detail to gather user feedback. One of the 40 wireframe diagrams that was included in the design package is shown in Figure 25.

![Figure 25: User Interface Prototype Example: ODOT TripCheck Wireframe Diagram](http://ops.fhwa.dot.gov/publications/seitsguide/seguide.pdf)

### Detailed Design

There are many ways to document software detailed design. Most commonly, it is portrayed using object-oriented techniques and the Unified Modeling Language\(^\text{17}\), but any technique that the implementation team selects is fine as long as it is detailed enough to support software construction and clear enough to support peer reviews and walkthroughs.

Table 12 is an example of a detailed design for part of the Shadow software that works behind the scenes to keep the traffic information on the ODOT TripCheck website up to date. Note that the interface is defined and that loosely structured program design language (PDL) is used to define the algorithm that is used to process transactions. If much of this appears to be gibberish to you, you are not alone. This is why many agencies use software specialists to provide an independent review of the detailed software development artifacts for higher risk software projects on their behalf.

\(^\text{17}\)There are many resources available if you want to learn more about UML; [www.uml.org](http://www.uml.org) is a good place to start.
Table 12: Detailed Software Design Example: ODOT TripCheck Software Class Definition

<table>
<thead>
<tr>
<th>Class Name:</th>
<th>clsShadow::ProcessTransactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Class Method</td>
</tr>
<tr>
<td>Scope:</td>
<td>Public</td>
</tr>
<tr>
<td>Arguments:</td>
<td>n/a</td>
</tr>
<tr>
<td>Return Value:</td>
<td>n/a</td>
</tr>
<tr>
<td>Error Messages:</td>
<td>Error reading shadow table</td>
</tr>
<tr>
<td>Error Handling:</td>
<td>True</td>
</tr>
<tr>
<td>Files Accessed:</td>
<td>n/a</td>
</tr>
<tr>
<td>Files Changed:</td>
<td>n/a</td>
</tr>
<tr>
<td>Methods Called:</td>
<td>n/a</td>
</tr>
<tr>
<td>Narrative:</td>
<td>Processes any transactions waiting in the Shadow Table.</td>
</tr>
</tbody>
</table>

Pseudocode(PDL):

```
Open Connection to Shadow Table
Retrieve all transactions
Do While Not Rs.Eof
    Create a collection of clsTransaction objects
Loop
If we have events to process...
    Raise Event NewTransactions(clsTransactions)
Clean Up
```
4.6 Software/Hardware Development and Testing

*In this step:* Hardware and software solutions are created for the components identified in the system design. Part of the solution may require custom hardware and/or software development, and part may be implemented with off-the-shelf items, modified as needed to meet the design specifications. The components are tested and delivered ready for integration and installation.

<table>
<thead>
<tr>
<th>OBJECTIVES</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Develop and/or purchase hardware and software components that meet the design specifications and requirements with minimum defects</td>
</tr>
<tr>
<td>- Identify any exceptions to the requirements or design specifications that are required</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sources of Information</td>
</tr>
<tr>
<td>- System and subsystem requirements</td>
</tr>
<tr>
<td>- System design</td>
</tr>
<tr>
<td>- Off-the-shelf products</td>
</tr>
<tr>
<td>- Industry standards</td>
</tr>
<tr>
<td>- Unit/Device Test Plans</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Activities</td>
</tr>
<tr>
<td>- Plan software/hardware development</td>
</tr>
<tr>
<td>- Establish development environment</td>
</tr>
<tr>
<td>- Procure off-the-shelf products</td>
</tr>
<tr>
<td>- Develop software and hardware</td>
</tr>
<tr>
<td>- Perform unit/device testing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Results</td>
</tr>
<tr>
<td>- Software/hardware development plans</td>
</tr>
<tr>
<td>- Hardware and software components, tested and ready for integration</td>
</tr>
<tr>
<td>- Supporting documentation (e.g., training materials, user manuals, maintenance manuals, installation and test utilities)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REVIEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proceed only if you have:</td>
</tr>
<tr>
<td>- Conducted technical reviews of the hardware/software</td>
</tr>
<tr>
<td>- Performed configuration/quality checks on the hardware and software</td>
</tr>
<tr>
<td>- Received all supporting documentation</td>
</tr>
<tr>
<td>- Verified that unit/device testing has been successfully completed</td>
</tr>
</tbody>
</table>
4.6.1 Overview

Although hardware and software development may be the first task that comes to mind when thinking about an ITS project, the systems engineering approach focuses on the preceding requirements and design steps and on the integration, verification, and validation steps to follow.

This is where the investment in a clear set of requirements and a good system design should begin to pay dividends. The systems engineering process now provides technical oversight as an implementation team of specialists fabricates the hardware and writes the software. This is a highly iterative process, particularly for software, where key features may be incrementally implemented, tested, and incorporated into the baseline over time. Progress is monitored through a planned series of walkthroughs, inspections, and reviews, as shown in Figure 26.

Although the systems engineering approach does not specify the mechanics of hardware and software development (this is left to the implementation team), the development effort is obviously critical to project success. **This is the time to build quality into the hardware/software and to minimize defects.** A common refrain in the software industry is that you can’t test quality into the software – you must build it in from the beginning. The systems engineering activities that are suggested in this chapter are intended to ensure that the implementation team builds quality into their products.

In practice, most of the hardware that is used for ITS projects is purchased off the shelf. Software development is more prevalent, but many ITS projects include little or no software development. ITS projects that do not include custom hardware or software development acquire the necessary off-the-shelf hardware and software components at this step. Detailed specifications created as part of the detailed design step described in Section 4.5 are used to support the acquisition. The system components are acquired, and bench testing is performed to verify that they meet their specifications. In such cases, the detailed hardware/software development and unit testing described in this chapter are not required.

Custom software development for ITS projects has proven to be a relatively risky endeavor. This is why software development receives more attention than hardware development in this chapter. It is beyond the scope of this document to discuss specific software development techniques, but there are several clear factors that contribute to software development success:

- No matter how clear and unambiguous the requirements appear, it is almost certain that the software customer and the software implementation team will interpret some of the requirements differently. Requirements walkthroughs that are described in Section 4.4.2 help to mitigate this risk, but ultimately the customer/stakeholders will have to monitor the software as it is being developed to ensure that the development is proceeding in the right direction. Expect and plan for course corrections and requirements changes along the
way, at least until we discover the way to build the “perfect specification”. Ensure that the contract is flexible enough to have a couple of reviews and that it allows some visits or informal reviews with the developers to see how they are doing. This might be one of the project risks to include in your risk management plan. (See Section 5.3 for more information on risk management.)

Consider the following requirement:

“The system shall turn off the alarm when the user presses the ‘F6’ key.”

Even this seemingly clear, very specific requirement was subject to two interpretations. The customer assumed that a currently sounding alarm is turned off when the button is pressed, and the implementer assumed that the capability to sound an alarm is turned off. Even “good” specifications are subject to potential pitfalls like this.

- All documentation should be reviewed and approved. One of the biggest problems faced by system implementers is the customer’s failure to review documentation, which leads to a system at the end of the project that does not meet the customer’s expectations. If the documentation that is generated is not reviewed, then much of the benefit of systems engineering will not be realized. Depending on your background, you may need to find experts who can review more technical documentation on your behalf.

- Perhaps the best way to reduce software development risk is to proceed in small steps and build incremental software releases in short, successive time periods. Unlike a typical roadway project that can be fully specified and implemented all at once, complex software should be implemented incrementally, with months or even weeks between releases. Incremental, iterative development with frequent coordination and feedback is the best way to keep software development on track, particularly for projects where the requirements are not completely understood at the outset.

### 4.6.2 Key Activities

The hardware and software specialists implement and test each system component. Systems engineers play a supporting role, providing technical oversight on an ongoing basis to identify minor issues early, before they grow into large problems. The process works best when there is a close working relationship among the customer, the systems engineers (e.g., a consultant or in-house systems engineering staff), and the implementation team (e.g., a contractor or an in-house team). Each of the activity descriptions is followed by a discussion of the technical review and monitoring of that activity.

- **Plan software/hardware development** – The implementation team documents its development process, best practices, and conventions that will be used. The Software/Hardware Development plan should address development methods, documentation requirements, delivery stages, configuration control procedures, technical tracking and control processes, and the review process. The plan(s) should be reviewed by the customer and the broader project team.

The Software/Hardware Development plan should be reviewed and approved before development begins. Well-qualified implementation teams will already have proven processes in place that can be tailored for the specific project, so this shouldn’t be viewed as a burdensome activity. The intent is not to mandate a particular implementation process but to ensure that the implementation team has an established process that they will follow. An implementation team that doesn’t have a documented process is a red flag.
Establish development environment – The tools that are used to develop and test the software are selected, procured, and installed, including development tools, source control tools, third-party application libraries, and test simulators. Every tool that is used to support software development should be documented specifically enough so that the development environment can be replicated if necessary.

Although it is sometimes overlooked, the development environment is just as critical to future software maintenance as the actual detailed design documentation and source code. Every tool that is used to develop and test the software should be documented, including version information and complete documentation of any customization or extensions. If this is a custom development and you have paid for the tools, include the development environment as a project deliverable.

A peer review or inspection can be used to verify that the development environment is adequate and accurately documented. Once established, the development environment should be placed under configuration management (discussed in Section 5.4) so that changes to the environment are tracked. Seemingly minor changes like application library upgrades or operating system service pack upgrades can cause problems later if they are not controlled and tracked.

Procure off-the-shelf products – Off-the-shelf products are procured based on the product specifications developed in the detailed design step (see Section 4.5).

Delay procurement until the products are actually required to support the implementation. Too much lead time can result in hardware or software that becomes outdated before it can be integrated into the project. Too little lead time could cause procurement delays that impact the project schedule.

Develop software and hardware – The software is written and the hardware is built based on the detailed design. The current state of the practice is to develop the software incrementally and release it in stages. The initial releases implement a few core features, and subsequent releases add more features until all requirements are satisfied. For example, a TMC project might first implement a basic dynamic message sign capability and demonstrate its ability to post messages to the sign and to monitor sign status. Then, more advanced message scheduling and message library management functions could be implemented. This incremental approach enables early and ongoing feedback between the customer and the implementation team. If this approach is used, then a staged delivery plan, which defines the order in which the software will be developed and the staged release process, should be included in the Software Development Plan.

Releases will be developed, tested, and made available to selected users for feedback. Providing feedback on interim releases is only part of the technical oversight that should be performed. Code inspections and code walkthroughs should also be used to check the software quality; these are the only ways to ensure that the software is well structured, well documented, and consistently follows the coding standards and conventions. Independent reviewers with software expertise should be used to help verify software quality on the customer’s behalf if the customer agency does not have the right expertise.

Most project managers who have managed software development efforts are familiar with the “90% complete” syndrome, in which software developers quickly reach “90% complete” status but the development effort then languishes as the final 10% takes much more work than anticipated. Project tracking should be based on discrete, measurable milestones instead of arbitrary “% complete” estimates from the software developers. For example, instead of tracking the developer’s estimated “% complete”, set up a monitoring
system that gives credit for completed software only when the piece of code has been successfully tested and integrated into the next release.

- **Develop supporting products** – Enabling products, such as training materials, user and maintenance manuals, online help, and installation and conversion software, are developed. It is natural to focus on the hardware and software in the “end product”, but you also must develop and account for all ancillary products that are needed in a working system.

  Like the end-product hardware and software components, the supporting products can also be developed in stages and released incrementally to encourage early customer feedback.

- **Perform unit/device testing** – The software and hardware components are thoroughly tested to identify as many defects as possible. The first line of defense is the software developer, who should step through and test every line of code, including all exception and error cases. Additionally, a series of test cases are devised that will exercise the hardware/software component; these test cases are documented in a unit verification plan. After the software is complete and thoroughly debugged by the developer, the test cases are used to test the hardware/software and the results are documented. Identified defects are analyzed and corrected, and testing is repeated until all known defects are either fixed or otherwise resolved. Defect correction may be relatively simple or may include redesign of sections of code that are determined to be error-prone.

  While the developers will conduct their own tests to identify and fix as many defects as possible, experience shows that the test cases and formal tests should be conducted by an independent party, either within the implementation team or from another organization. The reason for this independence is obvious if you look at the objectives of the software developer and the software tester. The primary objective for the tester is to break the software while the primary objective of the developer is the exact opposite – to make the software work. Few individuals can effectively wear both of these hats. The degree of independence between the developer and the tester (i.e., different people in the same department, different departments, or different companies) and the level of formality in unit testing should be commensurate with the criticality of the software and the size of the project.

  The unit verification plan should be reviewed to confirm that it will thoroughly test the hardware/software unit. The traceability matrix should be updated to identify the components, test cases, and test status. The testing should be tracked as it progresses to verify that defects are being identified and addressed properly. A testing process that identifies few defects could indicate excellent software or an incomplete or faulty testing process. Use scheduled technical reviews to understand the real project status. You can monitor the rate at which defects are being discovered to estimate the number of remaining defects and make an educated decision about when the hardware/software will be ready for release.

### 4.6.3 Outputs

This step results in hardware and software components that are tested and ready for integration and verification. Artifacts of the development process are also delivered, including the Software/Hardware Development Plans, development environment documentation, unit test results, change control records, and supporting products and documentation. A record of the technical reviews that were conducted should also be included in the project documentation.
4.7 Integration and Verification

*In this step:* The software and hardware components are individually verified and then integrated to produce higher-level assemblies or subsystems. These assemblies are also individually verified before being integrated with others to produce yet larger assemblies, until the complete system has been integrated and verified.

<table>
<thead>
<tr>
<th>OBJECTIVES</th>
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</thead>
<tbody>
<tr>
<td>Integrate and verify the system in accordance with the high-level design, requirements, and verification plans and procedures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confirm that all interfaces have been correctly implemented</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confirm that all requirements and constraints have been satisfied</td>
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<td></td>
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</table>

<table>
<thead>
<tr>
<th>INPUT Sources of Information</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>System Requirements document</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-level design specifications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detailed design specifications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardware and software components</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integration plan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System and Subsystem Verification Plans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsystem Acceptance Plans</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PROCESS Key Activities</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Add detail to integration and verification plans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Establish integration and verification environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform integration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform verification</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>OUTPUT Process Results</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration plan (updated)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verification plan (updated)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integration test and analysis results</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verification results, including corrective actions taken</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REVIEW Proceed only if you have:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Documented evidence that the components, subsystems, and system meet the allocated requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Documented evidence that the external and internal interfaces are working and consistent with the interface specifications</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.7.1 Overview

In this step, we assemble the system components into a working system and verify that it fulfills all of its requirements. Assembling a puzzle is a nice, simple analogy for this step, but the challenge in an ITS project “puzzle” is that you may find that not all of the pieces are available at the same time, some won’t fit together particularly well at first, and there will be pressure to change some of the pieces after you have already assembled them. The systems engineering approach provides a systematic process for integration and verification that addresses the challenges and complexity of assembling an ITS system.

Integration and verification are iterative processes in which the software and hardware components that make up the system are progressively combined into subsystems and verified against the requirements, as shown in Figure 27. This process continues until the entire system is integrated and verified against all of its requirements. This is the opposite of the decomposition that was performed during the Requirements and Design steps, which is reflected in the symmetry between the left and right sides of the “V”. Components that are identified and defined on the left side of the “V” are integrated and verified on the right.

In systems engineering, we draw a distinction between verification and validation. Verification confirms that a product meets its specified requirements. Validation confirms that the product fulfills its intended use. In other words, verification ensures that you “built the product right”, whereas validation ensures that you “built the right product”. This is an important distinction because there are lots of examples of well-engineered products that met all of their requirements but ultimately failed to serve their intended purpose. For example, a bus rapid transit system might implement a signal priority capability that satisfies all of its requirements. This system might not serve its intended purpose if the traffic network is chronically congested and the buses are never actually granted priority by the signal control system when they need it most. Verification is discussed in this section; system validation is described in Section 4.9.

Integrating and verifying the system are key systems engineering activities. The software and hardware specialists who led the previous step are also involved and provide technical support as their components are integrated into the broader system. Stakeholders should also be materially involved in verification, particularly in the system verification activities. As the verification proceeds from detailed component verification to end-to-end system verification, the implementation team becomes less involved and the stakeholders become more involved. The systems engineering activity provides continuity to the process.

4.7.2 Key Activities

Integrating and verifying the system include basic planning, preparation, and execution steps, described as follows:
Add detail to the integration and verification plans – Recall that integration and verification planning actually began on the left side of the “V”. A technique for verifying every requirement was identified as the requirements were specified, and a plan for verifying each requirement was documented. As the system design was defined, the plan for integrating the system components was developed. Detail was added to the general plan when the system was implemented, and the order in which project components and other required resources would be available was defined. The connections between the requirements, system components, and verification techniques were documented in a traceability matrix that was updated as the project development progressed.

The integration plan defines the order in which the project components are integrated with each other and with other systems. Each integration step includes tests that verify the functionality of the integrated assembly, with particular focus on the interfaces. For less complex projects, the integration plan can be informal. For complex projects, there will have to be careful planning so that the system is integrated in efficient, useful increments consistent with the master schedule.

The verification plan is expanded into procedures that define the step-by-step process that will be used to verify each component, subsystem, and system against its requirements. For efficiency, test cases are identified that can be used to verify multiple requirements. Each test case includes a series of steps that will be performed, the expected outputs, and the requirements that will be verified by each step in the test case.

The systems engineering analysis requirements identified in FHWA Rule 940.11/FTA Policy Section VI include “identification of … testing procedures”, which are the same as the verification procedures that are described here.

Every round of verification that is performed as the system is integrated should be thorough so that defects are identified as early and at as low a level as possible. It is much easier to isolate a defect during component-level verification than it is during system verification, when the entire system is assembled and many different components could be contributing to the problem. To put it in plain language, it is much easier to find the needle before you have assembled a haystack around it.

Establish the integration and verification environment – The tools that will be used to support integration and verification are defined, procured, and/or developed. For complex systems, this could include simulators that are used to mimic operational interfaces, test equipment that is used to inject failures and monitor system responses, etc. The verification environment simulates the operational environment as faithfully as possible and allows portions of the system to be tested before all components are completed.

If test and simulation tools are used to support system verification, then these tools should first be verified with the same care as the system. Verifying a system using a simulator that has not been verified could result in invalid results or compensating errors in which a defect in the end product is masked by a defect in the verification tool.

Perform integration – The system is progressively integrated based on the high-level design and the integration plan. The system components are integrated with each other and with other interfacing systems. Integration tests are used to verify that the components and higher-level assemblies work together properly and do not interfere with one another. Integration tests are used to exercise the interfaces and verify that all interfaces are implemented according to the documentation. Proposed changes to the baseline high-level design, including any required changes to the interface documentation, are identified.
Integration and Verification

- **Perform verification** – Every requirement is verified using the test cases defined in the verification procedures. System requirements and the related subsystem- and component-level requirements may be verified several times as verification progresses bottoms-up from component to subsystem to system-level verification. For example, a requirement that the system “shall blank a selected dynamic message sign on user command” might be verified at several different levels. The capability of the sign to blank itself would be verified at the dynamic message sign (DMS) component level. The capability of the user interface to accept and relay a “blank sign command” might be tested at the subsystem level, and finally an end-to-end system test would be used to verify that the sign actually blanks on user command. The fully integrated system should be verified at the integrator’s facilities before it is installed at the customer’s site.

There are four basic techniques that are used to verify each requirement:

- **Test**: Direct measurement of system operation. Defined inputs are provided and outputs are measured to verify that the requirements have been met. Typically, a test includes some level of instrumentation. Tests are more prevalent during early verification, when component-level capabilities are being exercised and verified.

- **Demonstration**: Witnessing system operation in the expected or simulated environment without need for measurement data. For example, a requirement that an alarm is issued under certain conditions could be verified through demonstration. Demonstrations are more prevalent in system-level verification when the complete system is available to demonstrate end-to-end operational capabilities.

- **Inspection**: Direct observation of requirements such as construction features, workmanship, dimensions and other physical characteristics, and software language.

- **Analysis**: Verification using logical, mathematical, and/or graphical techniques. Analysis is frequently used when verification by test would not be feasible or would be prohibitively expensive. For example, a requirement that a website support up to 1,000 simultaneous users would normally be verified through analysis.

As each test case is performed, all actions and system responses are recorded. Unexpected responses are documented and analyzed to determine the cause and to define a plan of action, which might involve repeating the test, revising the test case, fixing the system, or even changing the requirement. Any changes to the test cases, the requirements, or the system are managed through the configuration management process.

It is important to keep strict configuration control over the system components and documentation as you proceed through verification. The configuration of each component and the test-case version should be verified and duly noted as part of the verification results. It is human nature to want to find and fix a problem “on the spot”, but it is very easy to lose configuration control when you jump in to make a quick fix. (See Section 5.4 for more information about configuration management.)

As verification proceeds, you normally will have to retest each portion of the system more than once. For example, a new software release that adds new capabilities or fixes previously identified defects may be produced. It is important not only to verify the new features or bug fixes when verifying the new release but also to do regression testing to verify that the portion of the software that used to work still does. Regression tests are important because experience shows that old defects may reappear in later releases or that a fix to one part of the software may break another part. For large projects, automated testing tools can be used to automatically run a suite of regression tests to fully test each new software release.
Resist the temptation to scale back verification activities due to budget or schedule constraints. This would be false economizing because defects that slip through will be even more expensive to fix later in the system life cycle. As previously noted, it is most efficient to identify defects early in the verification process. This approach also minimizes the number of issues that will be identified during system verification, which is the most formal and most scrutinized verification step. Issues that occur during a formal system verification that is witnessed by stakeholders can undermine confidence in the system. Be sure to run the system verification test cases beforehand to the extent possible to reduce the risk of unexpected issues during formal system verification.

### 4.7.3 Outputs

Integration and verification result in a documentation trail showing the activities that were performed and their results. The outputs include:

- **Integration plan (updated)** – This plan defines the sequence of steps that were performed to integrate the system. It also defines the integration tests that were performed to test the interfaces in detail and generally test the functionality of the assembly.

- **Verification plan (updated) and procedures** – This plan documents the approach that was used to verify each of the system and subsystem requirements. The plan identifies test cases that were used to verify each requirement and general processes that were used to conduct the test cases and deal with verification issues. Verification procedures elaborate each test case and specify the step-by-step actions and expected responses. The traceability matrix ties the requirements to the design components and the test cases.

- **Integration test and analysis results** – This is a record of the integration tests that were actually conducted, including analysis and disposition of any identified anomalies.

- **Verification results** – This is a summary of the verification results. It should provide evidence that the system/subsystem/component meets the requirements and identify any corrective actions that were recommended or taken as a result of the verification process.

### 4.7.4 Examples

Many verification plans that have been developed for ITS projects are available on the Internet. Although they have many different titles – integration test plans, functional test plans, verification plans – they have similar content. For example, Table 13 is an excerpt from a functional test plan that was used to test the Oregon DOT TripCheck website. The script in the table lists each action that the tester should take and the expected result from the system in a step-by-step procedure that tests links in a website navigation panel.

**Table 13: Verification Procedure Example: ODOT TripCheck Functional Test Plan (Excerpt)**

<table>
<thead>
<tr>
<th>STEP</th>
<th>INPUT</th>
<th>SCRIPT</th>
<th>EXPECTED RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>Test winter travel links</td>
<td></td>
</tr>
<tr>
<td>1.a</td>
<td>Select Chain Laws</td>
<td>Opens: Pages/RCMap.asp?curRegion=ChainLaws</td>
<td></td>
</tr>
<tr>
<td>1.b</td>
<td>Select Traction Tires</td>
<td>Opens: Pages/RCMap.asp?curRegion=TractionTires</td>
<td></td>
</tr>
<tr>
<td>1.c</td>
<td>Select Minimum Chain Requirements</td>
<td>Opens: Pages/RCMap.asp?curRegion=MinChainReqs</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>None</td>
<td>Test related links</td>
<td>Each link opens a browser window with an external URL</td>
</tr>
</tbody>
</table>
Table 14 is a verification procedure from a Maryland Chart II Integration Test Plan that includes a bit more background for each test case in a slightly different format.

Table 14: CHART II Integration Test Plan (Excerpt)

<table>
<thead>
<tr>
<th>Test ID: General 1</th>
<th>Test Start Date</th>
<th>Test End Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose: To show that a valid username/password is accepted for logging in to CHART II within 15 seconds, and that an invalid combination is rejected. In addition, this test case also demonstrates that the system returns control to the user and the user is not prevented from performing activities in other windows on the desktop. CHART-27, CHART-10, CHART-21, CHART-275, CHART-276, CHART-29, CHART-26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test Pre-Conditions: This test assumes a valid username and password of a user in the CHART2 system is known.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test Step No.</th>
<th>Test Steps</th>
<th>Expected Behavior</th>
<th>Results As Expected (Y/N)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Click on the Login button on the GUI toolbar.</td>
<td>An hourglass should display immediately, within 5 seconds, till the login window is displayed. Then, you should be prompted for a UserID and password.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Attempt to login with an invalid username or password.</td>
<td>The system should popup an error message indicating that an invalid user ID or password was specified.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Attempt to login with the valid UserID and password.</td>
<td>The system should indicate that the user is logged in by showing Operations Center:Username on the GUI toolbar window.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Click on Navigator</td>
<td>Navigator window is opened.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Click on DMS node</td>
<td>List of DMSs is displayed on the right hand side of the Navigator.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reports are generated that document the actual results of the verification tests that were performed. Table 15 is a brief excerpt from a test result report for the desktop application that is used by ODOT to update data on the TripCheck website. Each row in the table summarizes the results for each test case. This excerpt was selected because it includes one of the few test cases in this report in which the actual results did not match the expected results. Note that in Test 2, an error occurred that exposed a software defect that had to be fixed. Identification of defects like this before the system is operational is one of the key benefits of a thorough verification process.

Table 15: ODOT TripCheck 2.0 System Test Results (Excerpt)

<table>
<thead>
<tr>
<th>DESCRIPTION OF TEST</th>
<th>INPUT DATA</th>
<th>EXPECTED RESULTS</th>
<th>ACTUAL RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Enter an incident of type Herbicide Application.</td>
<td>An incident of type Herbicide Application.</td>
<td>Does not appear in TripCheck.</td>
<td>As expected, incident did not go into the transaction table.</td>
</tr>
<tr>
<td>2 Enter an incident that is then put on hold.</td>
<td>An incident that is on hold.</td>
<td>Does not appear in TripCheck.</td>
<td>When incident is put on hold a delete transaction is entered in the shadow table. An error occurred with this delete transaction and the incident remained on TripCheck.</td>
</tr>
<tr>
<td>3 Put the incident from step 2 back into active status in HTCRS.</td>
<td>Incident is on TripCheck.</td>
<td>As expected.</td>
<td></td>
</tr>
</tbody>
</table>
4.8 Initial Deployment

In this step: The system is installed in the operational environment and transferred from the project development team to the organization that will own and operate it. The transfer also includes support equipment, documentation, operator training, and other enabling products that support ongoing system operation and maintenance. Acceptance tests are conducted to confirm that the system performs as intended in the operational environment. A transition period and warranty ease the transition to full system operation.

<table>
<thead>
<tr>
<th>OBJECTIVES</th>
<th>• Uneventful transition to the new system</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT Sources of Information</td>
<td>• Integrated and verified system, ready for installation</td>
</tr>
<tr>
<td></td>
<td>• System Acceptance Plan</td>
</tr>
<tr>
<td>PROCESS Key Activities</td>
<td>• Plan for system installation and transition</td>
</tr>
<tr>
<td></td>
<td>• Deliver the system</td>
</tr>
<tr>
<td></td>
<td>• Prepare the facility</td>
</tr>
<tr>
<td></td>
<td>• Install the system</td>
</tr>
<tr>
<td></td>
<td>• Perform acceptance tests</td>
</tr>
<tr>
<td></td>
<td>• Transition to operation</td>
</tr>
<tr>
<td>OUTPUT Process Results</td>
<td>• Hardware and software inventory</td>
</tr>
<tr>
<td></td>
<td>• Final documentation and training materials</td>
</tr>
<tr>
<td></td>
<td>• Delivery and installation plan, including shipping notices</td>
</tr>
<tr>
<td></td>
<td>• Transition Plan with checklists</td>
</tr>
<tr>
<td></td>
<td>• Test issues and resolutions</td>
</tr>
<tr>
<td></td>
<td>• Operations and maintenance plan and procedures</td>
</tr>
<tr>
<td>REVIEW Proceed only if you have:</td>
<td>• Formally accepted the system</td>
</tr>
<tr>
<td></td>
<td>• Documented acceptance test results, anomalies, and recommendations</td>
</tr>
</tbody>
</table>
4.8.1 Overview

Up to this point, the system has been tested primarily in a lab environment. The next step is to ship the system to the actual deployment site(s), install and check it out, and make sure the system and personnel are ready to transition to system operations and maintenance (O&M), as shown in Figure 28.

Larger systems may be installed in stages. For example, a closed-circuit television (CCTV) camera network may be built out incrementally over the course of several years and several projects. This may be done to spread the costs across several fiscal years or to synchronize with other construction projects in the region. In other cases, phased deployment may be performed to mitigate risk by deploying the essential core of the system and then adding features over time. If it is necessary to deploy the system in stages, whether due to funding constraints, to mitigate risk, or to synchronize with other projects, it is important to understand the dependencies between successive deployments and to prioritize the projects accordingly.

4.8.2 Key Activities

The following tasks are cooperatively performed to deliver, install, and transition the system to full operational status:

- **Plan for system installation and transition** – This step represents the handoff of the tested system from the project team to the O&M team in the field. The deployment sites must be prepared, the system must be delivered and installed at each site and tested, and O&M staff must be trained. All of this is documented in a System Delivery and Installation Plan. If the new system is replacing an existing system, a smooth transition will be planned and documented in a Transition Plan, including a backup strategy to revert to the existing system just in case the new system does not operate as intended. Each of these plans is further detailed below.

The deployment strategy should take into consideration the complexity of the system, whether it will be deployed at multiple sites, and, if so, the order of the deployments. It might be a good idea to bring up a minimal configuration or a single installation at first and to add further functionality and other sites once the initial installation is operational.

- **Deliver the system** – The system must be physically moved from the development and test labs to the actual deployment site(s). In preparation for this, a complete set of documentation will be developed by the engineering team and coordinated with the site O&M team. This documentation will include all the logistical details for transporting the hardware and software, any facility modifications that may be necessary, personnel assignments for installation, and installation instructions. You should even include shipping details such as the mode of transportation, shipping schedule, and shipping notices. Also include instructions regarding how the system should be handled after
delivery to the operational site. Perhaps it will be moved to a storage area if the site is not yet available, to a staging area, or to the final installation location(s). Key to the systems engineering process is advance planning, and this is especially true for delivery and installation since the system may actually change hands from the engineering team to the system owner.

Until delivery, the system’s components – the hardware and software – have been inventoried and under version control by the engineering team. Once delivered, however, ownership may change hands to the agency that will operate and maintain the system. The engineering and operating agencies should come to agreement ahead of time regarding who will maintain the inventory, the version of the software and hardware, any vendor maintenance agreements, and maintenance records to facilitate system delivery.

When the system is delivered, the O&M team should perform an initial inspection and preliminarily accept the system. This might be a formal review of the hardware/software inventory, a check of the documentation, or perhaps a start-up test. More extensive formal acceptance tests will be conducted once the system is fully installed.

- **Prepare the facility** – There are many war stories about the delivery of a system that didn’t quite fit the installation site – for example, server racks that wouldn’t fit through the equipment room door or CCTV cameras installed on 30-foot poles when DOT bucket trucks could reach no higher than 24 feet. For this reason, part of the planning process is to perform a site survey (including physical, electrical, communications, and lighting components) and prepare a site survey report and site installation plan. There might be some modifications required to the site or facility in order to accommodate the system, or something as simple as additional seating for personnel to operate the system. You should document any necessary site modifications in a site plan, execute the plan, and make sure the facility is ready to receive the system.

- **Install the system** – Following delivery of the system to a site that has been properly prepared and modified as necessary, the system will be installed. Sometimes, problems occur during system installation; make sure you’ve included a procedure for backing out all or part of the installed system in your installation plan. Following installation, verify that the system was installed correctly using documented verification procedures, also included in the installation plan. You could consider including the system operators in the installation tests since they’ll be objective and this will give them a chance to learn more about the system.

- **Perform acceptance tests** – Formal acceptance tests as identified in the System Acceptance Plan are performed by the customer agency following installation. Even if the development is done in-house, there should be a formal decision that the system is ready (i.e., accepted) to go operational.

- **Transition to operation** – After the system has been installed successfully at the final deployment site, the next step is to transition to full operation. For a new, standalone system, this can be a relatively uncomplicated effort. However, if the system must interoperate with other systems, as is the case when installing new AVL software on an existing computer-aided dispatch system, additional integration and testing may be necessary. Or perhaps the new system is replacing an existing system (e.g., an older signal control system). In this case, careful transition planning must take place to minimize the disruption to ongoing signal operations.

The first step is to create the Transition Plan, which clearly defines how the system will be transitioned to operational status. This plan should include the validation criteria; that is,
how are you going to know that the system is performing correctly once it is operational?
It is a good idea to include a series of checklists in the Transition Plan that identify all key
pieces that must be in place and working prior to switching over to full operation. If there
are still open issues found during system testing (and there likely will be), evaluate each of
them to determine whether or not they should be fixed or a work-around created prior to
placing the system into full operation. A formal review of the Transition Plan should be
held with the implementation team, the operations team, and other key personnel.

When transitioning to operation, especially when replacing an existing system, a
contingency back out plan should be included as part of the Transition Plan so that, in the
event that the new system does not operate correctly, you can revert to the older system
until the issues have been sorted out.

All operations and maintenance staff should be in place and properly trained. The
maintenance plans for the system should be reviewed by the O&M team; check to make
sure that all maintenance procedures and hardware/software maintenance records are in
place and adequate to properly maintain the system.

The operational procedures and any special equipment needed to operate or monitor the
system should be ready, tested, and operating correctly. It’s a good idea to take some
performance measurements on the system at this stage so that you can estimate
performance following transition to full operational status. Establish user accounts,
initialize databases or files as identified in the Transition Plan, and make sure that all test
data has been removed or erased. The system should be set to begin operations.

Some transitions to full operation can be complex, especially when an existing system that
many people use is being replaced. Just as we get annoyed when we can’t access the
Internet for a few hours, users may also become irritated if the system is down for any
period of time. You might want to consider planning the transition on a weekend or in the
evening if possible to cause the least disruption to system users. Also consider holding a
“dry run” so that everyone knows their role during the transition period and performs their
assigned task to make the transition as smooth as possible.

Finally, a transition readiness review meeting should be held with the O&M team, the
support personnel who are on hand to address last-minute issues, representatives from
other interfacing systems, the project sponsor, and other key personnel. Use the checklist
in the transition plan to assess system readiness. Only after all checklist items have been
declared as ready should the go-ahead be given for the system to transition to full
operational status.

Following transition, the team will quickly ramp down to include only the O&M
personnel. It might be advisable to keep a few system support personnel around through
the validation period so that any issues that arise in the early stages are resolved quickly.

4.8.3 Outputs

The primary output of this step is a fully installed system (in a facility or site modified to
meet the system requirements) that has been transitioned to operational status. To support
this effort, the following outputs should be generated:

- A hardware and software inventory, under configuration control, that includes
  versioning information, maintenance records and plans, and other property
  management information
- Final documentation and training materials
- Delivery and installation plan, including shipping notices
Initial Deployment

- Updated test plan and procedures
- Transition Plan with checklists
- Test issues and resolutions, and
- Operations and Maintenance Plan and procedures.

### 4.8.4 Examples

Deployment plans and installation plans can be complex documents for ITS projects that involve significant center and/or field equipment installation. Planning for deployment and installation must begin early in the project for such systems. For example, the Sunol Smart Carpool Lane Joint Powers Agency (JPA) developed a deployment plan as part of its Systems Engineering Management Plan during initial planning for the I-680 Smart Lane Project. This plan defines deployment activities (see Figure 29), roles and responsibilities, deployment personnel by position, installation equipment and tools, system documentation, and installation considerations such as safety, code and industry standards, planning requirements, weather accommodations, and shop drawing submittals. More detailed installation plans will be prepared by the system integrator based on this deployment plan.

<table>
<thead>
<tr>
<th>Pre-installation Activities as follows:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Verify civil and conduit work.</td>
</tr>
<tr>
<td>- Work with the JPA to finalize the Installation Plan, Installation Schedule, and other deployment documents.</td>
</tr>
<tr>
<td>- Ensure that all safety procedures are in place.</td>
</tr>
<tr>
<td>- Secure Caltrans Encroachment Permit.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Roadside Equipment Installation as follows:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- FasTrak Antennas and Readers.</td>
</tr>
<tr>
<td>- Tolling Zone Lane Controllers.</td>
</tr>
<tr>
<td>- Enforcement Beacons.</td>
</tr>
<tr>
<td>- Vehicle Detection System (VDS) Equipment.</td>
</tr>
<tr>
<td>- Closed Circuit TV (CCTV) Equipment.</td>
</tr>
<tr>
<td>- Communications Network Equipment.</td>
</tr>
<tr>
<td>- Other equipment as identified in the RFP.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TDC Equipment Installation as follows:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Trip Processor Hardware and Software.</td>
</tr>
<tr>
<td>- Customer Service Representative (CSR) Workstations.</td>
</tr>
<tr>
<td>- JPA Smart Lane website.</td>
</tr>
<tr>
<td>- Interface to the Bay Area Toll Authority (BATA) Regional Customer Service Center (RCSC).</td>
</tr>
<tr>
<td>- Interface to the Caltrans TMC.</td>
</tr>
<tr>
<td>- Interface to the CHP Enforcement Equipment.</td>
</tr>
<tr>
<td>- Other equipment as identified in the RFP.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Post-installation Activities as follows:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Verify that all of the equipment and software is installed properly</td>
</tr>
<tr>
<td>- Verify that each internal subsystem communicates properly to each other.</td>
</tr>
<tr>
<td>- Verify that all installed equipment and software operates properly.</td>
</tr>
</tbody>
</table>

Figure 29: I-680 Smart Lane Project Deployment Activities Overview
### 4.9 System Validation

**In this step:** After the ITS system has passed system verification and is installed in the operational environment, the system owner/operator, whether the state DOT, a regional agency, or another entity, runs its own set of tests to make sure that the deployed system meets the original needs identified in the Concept of Operations.

![System Validation Diagram]

<table>
<thead>
<tr>
<th>OBJECTIVES</th>
<th>▪ Confirm that the installed system meets the user’s needs and is effective in meeting its intended purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT</td>
<td>▪ Concept of Operations</td>
</tr>
<tr>
<td></td>
<td>▪ Verified, installed, and operational system</td>
</tr>
<tr>
<td></td>
<td>▪ System Validation Plan</td>
</tr>
<tr>
<td>PROCESS</td>
<td>▪ Update Validation Plan as necessary and develop procedures</td>
</tr>
<tr>
<td>Key Activities</td>
<td>▪ Validate system</td>
</tr>
<tr>
<td></td>
<td>▪ Document validation results, including any recommendations or corrective actions</td>
</tr>
<tr>
<td>OUTPUT</td>
<td>▪ System Validation Plan (update) and procedures</td>
</tr>
<tr>
<td>Process Results</td>
<td>▪ Validation results</td>
</tr>
<tr>
<td>REVIEW</td>
<td>▪ Validated that the system is effectively meeting its intended purpose</td>
</tr>
<tr>
<td>Proceed only if you have:</td>
<td>▪ Documented issues/shortcomings</td>
</tr>
<tr>
<td></td>
<td>▪ Established ongoing mechanisms for monitoring performance and collecting recommendations for improvement</td>
</tr>
<tr>
<td></td>
<td>▪ Made modifications to the Concept of Operations to reflect how the system is actually being used</td>
</tr>
</tbody>
</table>
4.9.1 Overview

A few readers may be surprised to see that there is another step in the “V” between initial deployment and operations and maintenance. After all, in the last few chapters we have already verified that the system meets all of its requirements, installed the system and trained the users, and the customer has successfully conducted acceptance tests and formally accepted the system. Aren’t we done?

The answer is: yes and no. Yes, the system has been put into operation and is beginning to be used for its intended purpose. No, we aren’t done. Now that the system is beginning to be used in the operational environment, we have our first good opportunity to measure just how effective the system is in that environment (i.e., system validation).

In systems engineering, we draw a distinction between verification and validation. Verification confirms that a product meets its specified requirements. Validation confirms that the product fulfills its intended use. The majority of system verification can be performed before the system is deployed. Validation really can’t be completed until the system is in its operational environment and is being used by the real users. For example, validation of a new signal control system can’t really be completed until the new system is in place and we can see how effectively it controls traffic.

Of course, the last thing we want to find is that we’ve built the wrong system just as it is becoming operational. This is why the systems engineering approach seeks to validate the products that lead up to the final operational system to maximize the chances of a successful system validation at the end of the project. This approach is called in-process validation and is shown in Figure 30. As depicted in the figure, validation was performed on an ongoing basis throughout the process:

- The business case for the project was documented and validated by senior decision makers during the initial feasibility study.
- User needs were documented and validated by the stakeholders (i.e., “Are these the right needs?”) during the Concept of Operations development.
- Stakeholder and system requirements were developed and validated by the stakeholders (i.e., “Do these requirements accurately reflect your needs?”).
- As the system was designed and the software was created, key aspects of the implementation were validated by the users. Particular emphasis was placed on validating the user interface design since it has a strong influence on user satisfaction.
Since validation was performed along the way, there should be fewer surprises during the final system validation that is discussed in this step. The system will have already been designed to meet the user’s expectations, and the user’s expectations will have been set to match the delivered system.

### 4.9.2 Key Activities

The system validation is the responsibility of the system owner and will typically be performed by the system users.

- **Update the Validation Plan and develop procedures** – An initial Validation Plan was created at the same time as the Concept of Operations earlier in the life cycle (see Section 4.3). The performance measures identified in the Concept of Operations forced early consideration and agreement on how system performance and project success would be measured. A Validation Plan was prepared that defined the consensus validation approach and the outcomes that should be measured.

  It is important to think about the desired outcomes and how they will be measured early in the process because some measures may require data collection before the system is operational to support “before and after” studies. For example, if the desired outcome of the project is an improvement in incident response times, then data must be collected before the system is installed to measure existing response times. This “before” data is then compared with data collected after the system is operational to estimate the impact of the new system. Even with “before” data, determining how much of the difference between “before” and “after” data is actually attributable to the new system is a significant challenge because there are many other factors involved. Without “before” data, validation of these types of performance improvements is impossible.

  In addition to objective performance measures, the system validation may also measure how satisfied the users are with the system. This can be assessed directly using surveys, interviews, in-process reviews, and direct observation. Other metrics that are related to system performance and user satisfaction can also be monitored, including defect rates, requests for help, and system reliability. Don’t forget the maintenance aspects of the system during validation – it may be helpful to validate that the maintenance group’s needs are being met as they maintain the system.

  Detailed validation procedures may also be developed that provide step-by-step instructions on how support for specific user needs will be validated. At the other end of the spectrum, the system validation could be a set time period when data collection is performed during normal operations. This is really the system owner’s decision – the system validation can be as formal and as structured as desired. The benefit of detailed validation procedures is that the validation will be repeatable and well documented. The drawback is that a carefully scripted sequence may not accurately reflect “intended use” of the system.

- **Validate the system** – The system is validated according to the Validation Plan. The system owner and system users actually conduct the system validation. The validation activities are documented and the resulting data, including system performance measures, are collected. If validation procedures are used, then the as-run procedures should also be documented.

  The measurement of system performance should not stop after the validation period. Continuing performance measurement will enable you to determine when the system becomes less effective. The desired performance measures should be reflected in the system requirements so that these measures are collected as a part of normal system
operation as much as possible. Similarly, the mechanisms that are used to gauge user satisfaction with the system (e.g., surveys) should be used periodically to monitor user satisfaction as familiarity with the system increases and expectations change.

Frequently, the way in which the system is used will evolve during initial system operation. Significant departures from anticipated procedures should also be noted and documented in the Concept of Operations. For example, consider an HOV reversible lane facility that uses system detectors to verify that all vehicles have exited the facility. During system operation, the agency may find that the reliability of system detectors is not as high as anticipated. To compensate, the agency adjusts its operating procedures to perform a physical tour of the facility prior to opening it up in the opposite direction. The agency should amend its ConOps to reflect this new way of operating the HOV facility.

**Document validation results** – The data resulting from the system validation is analyzed, and a validation report is prepared that indicates where needs were met and where deficiencies were identified. Deficiencies can result in recommended enhancements or changes to the existing system that can be implemented in a future upgrade or maintenance release. If an evolutionary development approach is used, the validation results can be a key driver for the next release of the product. (See Section 6.2.2 for more information on development strategies.)

Deficiencies of the project development process should also be reviewed to determine where the process may have fallen down, so that an improved process can be used on the next project. Without worrying about attribution to individuals, determine how a significant deficiency slipped through the process. Were the needs not properly specified? Were requirements incorrectly specified based on the needs? If so, were there opportunities for the stakeholders to walk through the requirements and identify the problem? A “lessons learned” review of the project development process at the conclusion of the system validation can be very valuable.

### 4.9.3 Outputs

System validation should result in a document trail that includes an up-to-date Validation Plan; validation procedures (if written); and validation results, including disposition of identified deficiencies. There are several industry and government standard outlines for validation plans, including IEEE Standard 1012\(^{18}\), which is intended for software verification and validation but is also applicable to broader system verification and validation. Note that this standard covers both verification and validation plans with a single outline.

### 4.9.4 Examples

There are few good examples of system validations that have been performed for ITS projects. Some of the best examples are evaluations that have been performed for field operational tests (FOTs), and other evaluations that have looked in detail at the benefits of ITS. For example, the evaluation of the ORANGES Electronic Payment Systems FOT initially identified system goals and then related them to quantitative and qualitative performance measures, as shown in Table 16. Each of the performance measures was then evaluated, in many cases using before-and-after study techniques, to determine whether the system goals were achieved. Figure 31 shows results supporting the transponder market penetration goal (Goal 2). This evaluation report is a good example of many validation

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techniques, including the collection of baseline data, before-and-after studies, statistical analysis, evaluation of other causal factors, and interview and survey activities.

Table 16: ORANGES Evaluation Goals and Performance Measures

<table>
<thead>
<tr>
<th>FOT Evaluation Goal</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase parking revenue</td>
<td>• Revenue received</td>
</tr>
<tr>
<td>2. Increase transponder market penetration</td>
<td>• Number of smart card users that newly acquire a transponder</td>
</tr>
<tr>
<td>3. Reduce transaction times</td>
<td>• Average transaction times</td>
</tr>
<tr>
<td>4. Increase prepaid revenue share</td>
<td>• % revenue prepaid</td>
</tr>
<tr>
<td>5. Reduce monthly pass distribution costs</td>
<td>• Procurement, inventory, delivery, commissions for any conventional passes made available on smart cards</td>
</tr>
<tr>
<td>6. Increase automated payment equipment uptime</td>
<td>• % equipment availability</td>
</tr>
<tr>
<td>7. Cardholders use the joint account</td>
<td>• Card use profiles</td>
</tr>
<tr>
<td></td>
<td>• Average prepaid balance</td>
</tr>
<tr>
<td></td>
<td>• Modal use profile</td>
</tr>
<tr>
<td>8. Understand customer perceptions</td>
<td>• Customer feedback</td>
</tr>
<tr>
<td>• General benefits</td>
<td></td>
</tr>
<tr>
<td>• Ease of use</td>
<td></td>
</tr>
<tr>
<td>• Convenience of revaluing</td>
<td></td>
</tr>
<tr>
<td>9. Understand operations/maintenance staff perceptions, including:</td>
<td>• Operations/maintenance staff feedback</td>
</tr>
<tr>
<td>• General benefits</td>
<td></td>
</tr>
<tr>
<td>• Reduced payment disputes</td>
<td></td>
</tr>
<tr>
<td>• Reduced transfer abuse</td>
<td></td>
</tr>
<tr>
<td>• Ease of customer use</td>
<td></td>
</tr>
<tr>
<td>• Maintenance</td>
<td></td>
</tr>
<tr>
<td>10. Understand planning/management staff perceptions, including:</td>
<td>• Planning/management staff feedback</td>
</tr>
<tr>
<td>• General benefits</td>
<td></td>
</tr>
<tr>
<td>• More comprehensive data collection</td>
<td></td>
</tr>
<tr>
<td>11. Understand interagency perceptions, including:</td>
<td>• Partnership feedback</td>
</tr>
<tr>
<td>• General institutional issues</td>
<td></td>
</tr>
<tr>
<td>• Interagency collaboration</td>
<td></td>
</tr>
</tbody>
</table>

Figure 31: ORANGES Evaluation – Cumulative Transponders Issued
### 4.10 Operations and Maintenance

**In this step:** Once the customer has accepted the ITS system, the system operates in its typical steady state. System maintenance is routinely performed and performance measures are monitored. As issues, suggested improvements, and technology upgrades are identified, they are documented, considered for addition to the system baseline, and incorporated as funds become available. An abbreviated version of the systems engineering process is used to evaluate and implement each change. This occurs for each change or upgrade until the ITS system reaches the end of its operational life.

<table>
<thead>
<tr>
<th>OBJECTIVES</th>
<th>Use and maintain the system over the course of its operational life</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT</td>
<td>System requirements (operations/maintenance requirements)</td>
</tr>
<tr>
<td>Sources of Information</td>
<td>Operations and Maintenance Plan and procedures</td>
</tr>
<tr>
<td></td>
<td>Training materials</td>
</tr>
<tr>
<td></td>
<td>Performance data</td>
</tr>
<tr>
<td></td>
<td>Evolving stakeholder needs</td>
</tr>
<tr>
<td>PROCESS</td>
<td>Conduct Operations and Maintenance Plan reviews</td>
</tr>
<tr>
<td>Key Activities</td>
<td>Establish and maintain all operations and maintenance procedures</td>
</tr>
<tr>
<td></td>
<td>Provide user support</td>
</tr>
<tr>
<td></td>
<td>Collect system operational data</td>
</tr>
<tr>
<td></td>
<td>Change or upgrade the system</td>
</tr>
<tr>
<td></td>
<td>Maintain configuration control of the system</td>
</tr>
<tr>
<td></td>
<td>Provide maintenance activity support</td>
</tr>
<tr>
<td>OUTPUT</td>
<td>System performance reports</td>
</tr>
<tr>
<td>Process Results</td>
<td>Operations logs</td>
</tr>
<tr>
<td></td>
<td>Maintenance records</td>
</tr>
<tr>
<td></td>
<td>Updated operations and maintenance procedures</td>
</tr>
<tr>
<td></td>
<td>Identified defects and recommended enhancements</td>
</tr>
<tr>
<td></td>
<td>Record of changes and upgrades</td>
</tr>
<tr>
<td></td>
<td>Budget projections and requests</td>
</tr>
<tr>
<td>REVIEW</td>
<td>Demonstrated that the system has reached the end of its useful life</td>
</tr>
<tr>
<td>Proceed only if you have:</td>
<td></td>
</tr>
</tbody>
</table>
4.10.1 Overview

Now that the ITS system is up and running, it enters a “steady state” period that lasts until the system is retired or replaced. During this period, operators, maintainers, and users of the system may identify issues, suggest enhancements, or identify potential efficiencies. New releases of hardware and software will be installed and routine maintenance will be performed. Approved changes and upgrades are incorporated into the system baseline using the systems engineering process, as shown in Figure 32. O&M personnel might also identify process changes that may streamline O&M activities. All changes to the processes should be documented.

Successful operations and maintenance of the system will lead to customer and user satisfaction; for example, the CCTVs will be online and fully functional at all times; rush-hour drivers will be able to obtain accurate, up-to-the-minute speed, accident, and construction reports before they head out the door; and transit vehicles will arrive on time. This is when the system benefits are realized.

4.10.2 Key Activities

In most systems, operations and maintenance is where the lion’s share of life-cycle costs are incurred. The key activities are performed periodically unless a change is considered severe and affects system performance dramatically.

- **Conduct Operations and Maintenance Plan reviews** – Operations and maintenance roles and required resources are defined in the Concept of Operations (see Section 4.3) and are refined as the system is developed. At this point, operations and maintenance personnel and the system sponsor should all be in agreement on the level of support to be provided with regard to staffing, frequency of technology refreshes (e.g., how often the software or hardware is upgraded to a new release), performance monitoring and reporting, processes for handling identified issues, and level of support provided to the end user.

- **Establish and maintain operations and maintenance procedures** – Although the processes to be used for identifying, tracking, resolving, and recording all system issues will have been established during the initial deployment step, specific detailed procedures will be further developed and maintained as efficiencies are identified. All personnel will be trained in the procedures and are responsible for their use.

- **Provide user support** – End users of your system, whether they are traffic management center operators or a person whose farecard is not working in the new farecard reader, need to be able to contact someone for user support. This support could be handled by a formal call center or perhaps only a person who performs the task during spare time via e-mail, depending on the type and complexity of the system to be supported. Either way, the user support personnel should be properly trained, should document all calls from
initiation through final resolution, and should have access to system experts if needed. These user support personnel should also provide periodic updates on user inquiries and resolutions.

A database that holds information about all user support inquiries can help you to review the types of calls that were received and to notice trends. If there seems to be a recurring problem or confusion about some aspect of the system, it could mean that a system modification should be considered.

- **Collect system operational data** – During earlier phases in the system life cycle, you will have determined how to collect system performance metrics and will have used the performance data to validate the system (see Section 4.9.2). During operations and maintenance, you should collect sufficient performance data to help you determine how well the system is operating over time. For example, in a transit management center, the on-time arrival performance data might be collected from the AVL software. If you are providing a website that displays incident and speed information, a positive response from a user who was asked whether the information was “helpful and accurate” could be collected. Feedback from operators and travelers will provide a measure of customer satisfaction. In-process reviews can be held periodically to review collected metrics, assess system performance, and identify potential system improvements.

- **Change or upgrade the system** – Like any computer system, planning for change and upgrade of your ITS system may start the day that the system is turned on. The system will evolve over its lifetime as stakeholder priorities change and technology advances. Changes can also result from user-reported issues and recommendations and from system improvements identified from the review of operational data. If you decided to deploy only part of the system during the initial deployment step, this is when you’ll incrementally add the rest of the system – whether it’s additional functionality or equipment at additional sites (e.g., additional CCTV deployment). (See Section 6.2.2 for more information on incremental development.)

All proposed changes should be prioritized and will require careful cost estimates, schedules, planning, testing, and coordination with operations and maintenance prior to installation. Each approved change will require a new system release level and should be coordinated between the O&M and development teams.

Each potential change to the system should be assessed by the affected stakeholders and the project sponsor to determine whether or not it should be incorporated. Before approving the change, you should clearly understand and document the effect that it will have on other parts of the system, on the operation of the system as a whole, and on the maintenance of the system. If you make this assessment early on by following the systems engineering process, you won’t discover a problem months later in the lab when the impact on the schedule and budget will be significantly higher.

Changes are approved and managed using the configuration management process defined in Section 5.4. You should use the systems engineering process, from Concept of Operations through design, verification, and installation, to add any approved change to the system. Basically, each change requires another, possibly abbreviated, pass through the “V”. Approved changes are typically aggregated into builds or releases, although you may want to introduce particularly complex changes individually.

Each build or release should be subjected to thorough verification testing prior to installation. There are many stories of “changes that affected only a few lines of code” that ultimately resulted in operational failure. It is important to run regression tests that
verify that a seemingly minor change in one part of the system didn’t have an unexpected
effect on another part of the system. Statements like “I didn’t change that area so there is
no need to test it” should be a red flag.

In many cases, the development and test lab that was available during the initial system
development may not be available once the system has been deployed. (It might even be
the system that was deployed!) Therefore, it’s common to establish a test environment to
test software product upgrades or minor fixes without interfering with the current
operational system.

- **Maintain configuration control of the system** – The deployed system is under
configuration control, so every time the system changes, even if only a minor software
patch was added, the system baseline must be updated. This means that all
documentation, databases, and any other operational data must also be updated. A project
library should be established that includes the latest baseline versions of all project
documentation. (Section 5.4 includes more information on configuration management.)

This is one area where state of the practice lags a bit in ITS. It is common for agencies to
require good configuration management practices during system development but to lose
configuration control after the system is delivered. For example, if you want to know the
configuration of a field controller at a particular location, you will have to take a trip to the
field and have a look inside the cabinet at many agencies.

- **Provide maintenance activity support** – A fully functional system should be available
for use at all times except for minimal prescheduled maintenance periods during off-
hours. Maintenance records on all equipment should be documented. Sufficient
equipment, materials, supplies, and spares should be in place, inventoried, and working
properly. The suggested quantities for each of these items should be included in the
maintenance plan prior to transitioning to full operational status.

Consider using a database tool or a similar property management application to help you
keep track of all equipment, together with maintenance records, maintenance schedules,
and so forth. Check it weekly and schedule the maintenance required.

### 4.10.3 Outputs

The current system configuration, including hardware, software, and operational information,
must be documented and maintained. A complete record of all system changes should
also be documented and readily available. This is especially helpful when trying to duplicate an
anomaly identified by a user or operator.

System performance reports should be generated, both from any installed automated performance
monitors and from user-support calls received. Trend analysis reports can be generated and
reviewed to identify system deficiencies.

- Document Maintenance and Operations Activities
- Develop and Maintain a Cost Database for Maintenance and Operations
- Analyze Maintenance and Operations Requirements
- Analyze Staffing Requirements for Maintenance and Operations Personnel
- Prioritize Maintenance Needs
- Develop and Maintain a Spare Parts Inventory
- Develop a Maintenance Plan
- Develop an Operations Manual

Figure 33: Kentucky ITS M&O Plan Best Practices
4.10.4 Examples

Operations and Maintenance Plans

The Kentucky Transportation Center developed a *Maintenance and Operations Plan for ITS in Kentucky* that provides recommendations for supporting and coordinating ITS maintenance and operations activities throughout the Kentucky Transportation Cabinet. It inventories ITS equipment and systems, identifies national best practices for operations and maintenance (see Figure 33), assesses current maintenance and operations practices in Kentucky, and makes recommendations. Many of the recommendations and best practices identified in the report will be relevant to other agencies. This broad agency-wide plan complements the detailed procedures that are used to operate and maintain individual systems.

Operations and Maintenance Procedures

Operations and maintenance procedures are detailed and don’t make particularly good reading unless you actually operate and maintain one of these systems, in which case they are indispensable. These manuals will be subject to relatively frequent changes as personnel will find errors and new and better ways to operate and maintain the system. A short excerpt from the CHART II O&M Procedures is shown in Figure 34.

Change and Upgrade Plans

Metro Transit in Seattle, Washington, upgraded its existing Transit AVL system to support transit traveler information systems as part of the Smart Trek program. To support this upgrade, detailed cost estimates were made based on systems engineering analysis of the AVL enhancements that would be required to support the traveler information objectives of the Smart Trek project. The estimate is shown in Table 17.

Table 17: Metro Transit AVL System Upgrade

<table>
<thead>
<tr>
<th>Equipment Description</th>
<th>Non-Recurring Costs</th>
<th>Recurring Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARI CPU Boards (Quantity: 1360)</td>
<td>$442,670</td>
<td></td>
</tr>
<tr>
<td>Modem Boards (Quantity: 1360)</td>
<td>$247,410</td>
<td></td>
</tr>
<tr>
<td>Termination Boards (Quantity: 1360)</td>
<td>$26,206</td>
<td></td>
</tr>
<tr>
<td>Labor to Retrofit MDU Units (Quantity: 1360)</td>
<td>$34,284</td>
<td></td>
</tr>
<tr>
<td>Delivery and Pickup of MDU and Cases (Quantity: 1360)</td>
<td>$3,834</td>
<td></td>
</tr>
<tr>
<td>Sales Tax on Above</td>
<td>$70,000</td>
<td></td>
</tr>
<tr>
<td>AVL Software</td>
<td>$250,000</td>
<td></td>
</tr>
<tr>
<td>MDU Test Tool (Software and Hardware)</td>
<td>$55,200</td>
<td></td>
</tr>
<tr>
<td>Contract Management Labor</td>
<td>$40,650</td>
<td></td>
</tr>
<tr>
<td>Basic System Maintenance (Hardware)</td>
<td></td>
<td>$10,000</td>
</tr>
<tr>
<td>Basic System Maintenance (Labor - 1 FTE)</td>
<td></td>
<td>$125,000</td>
</tr>
<tr>
<td>ISP Costs (3 lines)</td>
<td></td>
<td>$2,700</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$1,170,164</strong></td>
<td><strong>$137,700</strong></td>
</tr>
</tbody>
</table>

Figure 34: CHART II O&M Procedures
6.  ITS COMPONENTS DISCUSSION

The purpose of this section is to discuss the various components of ITS.

6.1  IRIS Software

IRIS (Intelligent Roadway Information System) is MnDOT’s Freeway Management System control software. IRIS development began in the late 1990s:

- In preparation for moving to the new TMC
- To move to NTCIP standards
- To support the increased number of field devices
- To take advantage of the open source operating systems and programs to eliminate significant ongoing licensing costs
- To lower the cost of computer hardware resources

The main features of IRIS are:

- Control of DMS (messages and travel times)
- Central control of ramp meters (input from about 5400 detectors)
- Control of cameras
- Control of lane control signals
- Delivery of data to MnPass HOT lanes

Figure 9 illustrates a screen from IRIS (DMS Control).

As an alternative to IRIS, commercial software is available that can do many of these functions, and that if you only have one or two types of devices, such as cameras and DMS, that often the device manufacturers have software that comes with the device that enables you to control just that type of device.
6.2 Detection

The control of traffic relates to the movement of vehicles and pedestrians. Since the volume of these movements generally varies at different times of the day, it is desirable to be able to detect approaching movements by placing one or more devices in the path of approaching vehicles or at a convenient location for the use of pedestrians.

Most advanced management systems and technologies in the ITS field rely on real-time traffic data, which reflects current conditions of traffic network. Traffic detection is a critical part in many advanced traffic systems, such as responsive ramp metering control and freeway incident detection.

Ramp metering control is the most common technology for reducing freeway congestion. The system measures freeway mainline capacity and traffic flow, and controls the rate at which vehicles enter the freeway mainline. Many studies show that ramp metering increases freeway efficiency, and reduces accidents and recurring congestion.

In freeway incident management systems, detectors generally are used to detect two types of congestion: recurring and nonrecurring. Recurring congestion is predictable at specific locations and times. Nonrecurring congestion is caused by random, temporary incidents, such as accidents and other unpredictable events.

Traffic detector technologies are continuously incorporated into new ITS application fields. For example, a portable intelligent transportation system provides traveler information in specific sites to improve safety and operation in work zones. A computerized control system integrates detector (speed sensor) and traveler information dissemination technologies. The control system automatically determines appropriate responses according to current traffic conditions.

Traffic detection systems play important roles not only in traditional transportation management but also in advanced transportation management systems. Traffic detection systems provide data to meet different needs in transportation fields.

6.2.1 Types of Detection

The different types of vehicle detectors available include but are not limited to the following types.

- Intrusive Detection (in-roadway)
  - Inductive loop detects a change in resonant frequency by the introduction of a metal in the magnetic field of the detection zone.
  - Magnetic/Magnetometer detects moving ferrous metal objects – pulse.
  - Microloop detects a change by moving metal in the earth’s magnetic field – pulse. Small inductive loop placed on top of a magnetometer.

- Non-Intrusive Detection (above roadway or sidefire)
  - Photo electric/Infrared detects a break in a beam of light – presence or pulse.
  - Radar/Microwave detects moving objects by sending and receiving electronic pulses – pulse.
  - Ultrasonic detects sound with a microphone – presence or pulse.
  - Video detects a change in a video pixel range – presence or pulse.

Non-intrusive detector technologies include active and passive infrared, microwave radar, ultrasonic, passive acoustic, and video image processing. Active infrared, microwave radar, and ultrasonic are active detectors that transmit wave energy toward a target and measure the reflected wave. Passive infrared,
passive acoustic, and video image processing are passive detectors that measure the energy emitted by a target or the image of the detection zone.

Some detectors record vehicles whether stopped or in motion. Others require that the vehicle be moving at a speed of at least 2 or 3 mph.

Normal loop or magnetic detectors will operate in either the pulse mode or presence mode. The magnetic detector produces a short output pulse when detection occurs, no matter how long the vehicle remains in the detection area. The normal loop is intended to produce a detector output for as long as a vehicle is in the field of detection.

Examples of controller functionality are; locking memory, non-lock, delay call, extend (stretch) call, and stop bar.

Another type of detection is the “speed analysis system”. This system is a hardware assembly composed of two loop detectors and auxiliary logic. The two loops are installed in the same lane a precise distance apart. A vehicle passing over the loops produces two actuations. The time interval between the first and the second actuation is measured to determine vehicle speed.

6.2.2 Inductive Loop Detectors

The most common type of vehicle detection device in use today is the inductive loop. This is a loop of wire imbedded in the pavement (saw cut in existing concrete or NMC loop in new concrete) carrying a small electrical current. When a large mass of metal passes over the loop, the magnetic field is disturbed and generates, or induces, a change in resonant frequency in the wire. This change in frequency is then recognized by the detector amplifier and signals the controller that a vehicle is present.

6.2.3 Video Detectors

Vehicle detection by video cameras is one of the most promising new technologies for non-intrusive large-scale data collection and implementation of advanced traffic control and management schemes. This concept provides real-time vehicle detection and traffic parameter extraction from images generated by video cameras. Major worldwide efforts have been directed at development of a practical device for image processing.

A video image processing system typically consists of the following components:

Image hardware - The imaging sensor is an electronic camera (conventional TV camera or an infrared camera) that overlooks a section of the roadway and provides the desired image information.

Processor - A processor determines vehicle presence or passage from images received by the camera. It also provides other traffic parameters preferably in real-time.

Software - Advanced tracking system software performs operations, detector programming, viewing of vehicle detections, and roadway surveillance.

Image processing detection systems can detect traffic in many locations (i.e., multiple spots) within the camera’s field of view. These locations can be specified by the user in minutes using interactive graphics, and can be changed as often as desired. This flexible detection is achieved by placing detection lines along or across roadway lanes on a TV monitor displaying the traffic scene (not physically placed in the pavement). Each time a vehicle image crosses these lines, a detection signal (presence or passage) is generated. The result is similar to that produced by loop detectors.

VIDS are advantageous in traffic detection since:
They are mounted above the road rather than in the road, providing multi-lane coverage along with installation and servicing advantages of traffic flow maintenance and personnel safety during detector repair.

Placement of vehicle detection zones on the road is not limited to a particular detection configuration. The configuration can be controlled and adjusted manually (by an operator with a computer terminal) or dynamically (by software) at any time, as a function of traffic flow.

The shape of the detection zone can be programmed for specific applications, such as freeway incident detection, detection of queue lengths (that cannot easily or economically be derived by conventional devices) and detection of turning patterns.

6.2.4 Radar/Microwave Detectors

Development of microwave radar during World War II enabled this technology to be applied to detection of vehicular traffic. The principles of operation involve microwave energy being beamed on an area of roadway from an overhead antenna, and the vehicle's effect on the energy detected. The antennas capture a portion of the transmitted energy reflected toward them by objects in the field of view. By direct comparison of transmitted energy with reflected energy from a moving vehicle, a Doppler beat note can be detected which in turn can be used to operate an output device. Use of continuous wave (CW) transmission and reliance on the use of a Doppler signal from the return wave eliminates the need for any gating or distance measurement, and, thereby, provides a simple detector responsive to vehicles moving through the field. By appropriate processing of information in the received energy, direct measurements of vehicle presence, occupancy, and speed can be obtained.

Continuous-wave Doppler microwave radar sensors transmit low-energy microwave radiation at a target area on the pavement and then analyze the signal reflected back to the detector. According to the Doppler principle, the motion of a vehicle in the detection zone causes a shift in the frequency of the reflected signal. This can be used to detect moving vehicles and to determine their speed. However, Doppler sensors cannot detect the presence of motionless objects, such as stopped vehicles.
### 6.2.5 Detector Technology Strengths and Weaknesses

#### Table 11 – Detector Technology Strengths and Weaknesses

[Source: FHWA Traffic Detector Handbook]

<table>
<thead>
<tr>
<th>Technology</th>
<th>Strengths</th>
<th>Weaknesses</th>
<th>Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductive loop</td>
<td>✓ Flexible design to satisfy large variety of applications. &lt;br&gt; ✓ Mature, well understood technology. &lt;br&gt; ✓ Large experience base. &lt;br&gt; ✓ Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, headway, and gap). &lt;br&gt; ✓Insensitive to inclement weather such as rain, fog, and snow. &lt;br&gt; ✓ Provides best accuracy for count data as compared with other commonly used techniques. &lt;br&gt; ✓ Common standard for obtaining accurate occupancy measurements. &lt;br&gt; ✓ High frequency excitation models provide classification data.</td>
<td>✓ Installation requires pavement cut. &lt;br&gt; ✓ Improper installation decreases pavement life. &lt;br&gt; ✓ Installation and maintenance require lane closure. &lt;br&gt; ✓ Wire loops subject to stresses of traffic and temperature. &lt;br&gt; ✓ Multiple loops usually required to monitor a location. &lt;br&gt; ✓ Detection accuracy may decrease when design requires detection of a large variety of vehicle classes.</td>
<td>Inductive loops can detect volume, presence, density, classification and speed.</td>
</tr>
<tr>
<td>Magnetometer (two-axis fluxgate magnetometer)</td>
<td>✓ Less susceptible than loops to stresses of traffic. &lt;br&gt; ✓Insensitive to inclement weather such as snow, rain, and fog. &lt;br&gt; ✓ Some models transmit data over wireless radio frequency (RF) link.</td>
<td>✓ Installation requires pavement cut. &lt;br&gt; ✓ Improper installation decreases pavement life. &lt;br&gt; ✓ Installation and maintenance require lane closure. &lt;br&gt; ✓ Models with small detection zones require multiple units for full lane detection.</td>
<td>Magnetic sensors can detect volume, classification, headway, presence and speed with algorithms or two sensors in a speed trap configuration.</td>
</tr>
<tr>
<td>Magnetic (induction or search coil magnetometer)</td>
<td>✓ Can be used where loops are not feasible (e.g., bridge decks). &lt;br&gt; ✓ Some models are installed under roadway without need for pavement cuts. However, boring under roadway is required. &lt;br&gt; ✓Insensitive to inclement weather such as snow, rain, and fog. &lt;br&gt; ✓ Less susceptible than loops to stresses of traffic.</td>
<td>✓ Installation requires pavement cut or boring under roadway. &lt;br&gt; ✓ Cannot detect stopped vehicles unless special sensor layouts and signal processing software are used.</td>
<td>Magnetic sensors can detect volume, classification, headway, presence and speed with algorithms or two sensors in a speed trap configuration.</td>
</tr>
<tr>
<td>Technology</td>
<td>Strengths</td>
<td>Weaknesses</td>
<td>Capability</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Microwave radar</td>
<td>✓ Typically insensitive to inclement weather at the relatively short ranges encountered in traffic management applications. ✓ Direct measurement of speed. ✓ Multiple lane operation available.</td>
<td>✓ Continuous wave (CW) Doppler sensors cannot detect stopped vehicles</td>
<td>Volume: Yes Presence: Yes Speed: Yes Classification: Yes (in terms of length)</td>
</tr>
<tr>
<td>Active infrared (laser radar)</td>
<td>✓ Transmits multiple beams for accurate measurement of vehicle position, speed, and class. ✓ Multiple lane operation available.</td>
<td>✓ Operation may be affected by fog when visibility is less than 20 feet (ft) (6 m) or blowing snow is present. ✓ Installation and maintenance, including periodic lens cleaning, require lane closure</td>
<td>Active infrared sensors can detect volume, presence, density, classification and speed.</td>
</tr>
<tr>
<td>Passive infrared</td>
<td>✓ Multizone passive sensors measure speed.</td>
<td>✓ Passive sensor may have reduced vehicle sensitivity in heavy rain, snow and dense fog. ✓ Some models not recommended for presence detection.</td>
<td>Infrared sensors are used for; volume, speed, and class measurement; detection of pedestrians in crosswalks; and transmission of traffic information to motorists.</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>✓ Multiple lane operation available.</td>
<td>✓ Environmental conditions such as temperature change and extreme air turbulence can affect performance. Temperature compensation is built into some models. ✓ Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles traveling at moderate to high speeds.</td>
<td>Most ultrasonic sensors operate with pulse waveforms and provide vehicle count, presence, and occupancy information.</td>
</tr>
<tr>
<td>Acoustic</td>
<td>✓ Passive detection. ✓ Insensitive to precipitation. ✓ Multiple lane operation available in some models.</td>
<td>✓ Cold temperatures may affect vehicle count accuracy. ✓ Specific models are not recommended with slow-moving vehicles in stop-and-go traffic.</td>
<td>Acoustic sensors measure vehicle passage, presence, and speed.</td>
</tr>
<tr>
<td>Technology</td>
<td>Strengths</td>
<td>Weaknesses</td>
<td>Capability</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Video image processor</td>
<td>✓ Monitors multiple lanes and multiple detection zones/lane. ✓ Easy to add and modify detection zones. ✓ Rich array of data available. ✓ Provides wide-area detection when information gathered at one camera location can be linked to another.</td>
<td>✓ Installation and maintenance, including periodic lens cleaning, require lane closure when camera is mounted over roadway (lane closure may not be required when camera is mounted at side of roadway). ✓ Performance affected by inclement weather such as fog, rain, and snow; vehicle shadows; vehicle projection into adjacent lanes; occlusion; day-to-night transition; vehicle/road contrast; and water, salt grime, icicles, and cobwebs on camera lens. ✓ Reliable nighttime signal actuation requires street lighting. ✓ Requires 30- to 50-ft (9- to 15-m) camera mounting height (in a side-mounting configuration) for optimum presence detection and speed measurement. ✓ Some models susceptible to camera motion caused by strong winds or vibration of camera mounting structure. ✓ Generally cost effective when many detection zones within the camera field of view or specialized data are required.</td>
<td>Video sensors can be used to collect volume, speed, presence, occupancy, density, queue length, dwell time, headway, turning movements, acceleration, lane changes and classification.</td>
</tr>
</tbody>
</table>

### 6.2.6 Vehicle Classification

Newer inductive-loop detector electronics units and loop configurations are capable of vehicle classification. The electronics module uses artificial neural network software to classify the traffic stream into the 23 categories depicted in Figure 10. The first 13 are the standard FHWA classes, while the remaining ones represent vehicles with unique characteristics.
Classification by axles:

Axle-based classification can include both the number of axles per-vehicle as well as axle spacing for each vehicle. The FHWA has defined 13 vehicle classes based on axle configurations, see Table 3. This vehicle classification scheme is generally followed and will be used for analysis in this evaluation.

Data from the piezoelectric sensors and loop detectors will be sent to an automatic data recorder (ADR) to combine and collect per-vehicle axle-based classification. The final result will be an accurate baseline measure of distance between each set of axles for each vehicle.
Table 12 – FHWA Vehicle Classification

<table>
<thead>
<tr>
<th>Class Bin</th>
<th>No. of Axles</th>
<th>Vehicle Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>Motorcycles</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Passenger Vehicles</td>
<td>Sedans, coupes and station wagons</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Other 2-axle, four tire single unit vehicles</td>
<td>Includes pickups, vans, campers, etc.</td>
</tr>
<tr>
<td>4</td>
<td>2 or more</td>
<td>Buses</td>
<td>Includes only traditional buses</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>2-Axle, 6-Tire, Single Unit Trucks</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>3-Axle Single Unit Trucks</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>4 or more</td>
<td>4-Axle Single Unit Trucks</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>3,4</td>
<td>4 or fewer Axle Single-TRailer Trucks</td>
<td>Semi with trailer</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>5-Axle Single-TRailer Trucks</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>6 or more</td>
<td>6 or more Axle Single-TRailer Trucks</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>4,5</td>
<td>5 or fewer Axle Multi-TRailer Trucks</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>6</td>
<td>6-Axle Multi-TRailer Trucks</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>7 or more</td>
<td>7 or more Axle Twin Trailer Semi Trucks</td>
<td></td>
</tr>
</tbody>
</table>

Classification by Length:
Although the axle-based classification system is used by many agencies, the FHWA does not require each state agency to use this system. Each state agency is allowed to develop its own classification system to suit its own needs. Some states are moving towards length-based detection. Because there is not yet a standard method to classify vehicles by length, a number of different agencies have recommended schemes. It is common to aggregate data into three to five length-based bins. The proposed length-based classification scheme is in Table 4. The table also maps the length bins to FHWA classes. These bins were determined based on a survey of multiple states and a 2005 MnDOT study that recommended the use of these bins. A per-vehicle analysis of length will be done for each sensor which can then be aggregated into any set of length-based bins.

Table 13 – Proposed Vehicle Length-based Classifications

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Vehicle Length</th>
<th>Vehicle Class</th>
<th>Axle to length adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorcycle</td>
<td>0 to 7 ft</td>
<td>1</td>
<td>0 ft</td>
</tr>
<tr>
<td>Passenger Vehicles (PV)</td>
<td>7 to 22 ft</td>
<td>2, 3</td>
<td>2.6 ft</td>
</tr>
<tr>
<td>Single Unit Truck (SU)</td>
<td>22 to 37 ft</td>
<td>4, 5, 6</td>
<td>12.8 ft</td>
</tr>
<tr>
<td>Combination Trucks (MU)</td>
<td>Over 37 ft</td>
<td>7-13</td>
<td>3.4 ft</td>
</tr>
</tbody>
</table>

One possible method for a length-based detection baseline is to use loop detectors. A study conducted for the Florida DOT compared loop-measured length with manually-measured length. The study found an
average length difference for each FHWA vehicle class measured by these two methods. This information can be applied to determine appropriate adjustments for each length-based bin. For the upcoming evaluation period, a modification can be made to loop system determined vehicle length to appropriately apply an adjustment to determine vehicle length. A preliminary estimate is shown in the right column of Table 4. These numbers will be refined when the mix of traffic at the NIT Test Site is known and more information about the Florida study is known.

A second possible baseline for length-based classification is to use piezoelectric sensors to determine the length between each axle of a given vehicle. A modification will be made to apply an adjustment to the length between the front and rear axle to determine vehicle length. The estimator value will be different for each FHWA classification. Project team members will determine these estimator values for each classification by measuring difference in axle length and total length of 10-20 vehicles in each class and then determining the average difference, which will be the estimator value for that class.

6.2.7 Speed Monitoring

Every Federal Fiscal Year (October through September), quarterly and annual speed monitoring reports are prepared by the OTST and submitted to the Federal Highway Administration (FHWA) Division Administrator. The results of this program are used to determine speed trends throughout the United States. Additional reports are sent to the Commissioner, all MnDOT districts, the MnDOT Library, Department of Public Safety, and the Legislative Reference Library.

Various methods are currently being used for the collection of data. Radar transmission devices, although useful in certain situations, are not used in the speed monitoring program due to manpower requirements. Below is a list of speed data collection devices.

- **Weigh-In-Motion (WIM) Stations** These devices are located throughout the State and collect a variety of data including the weight and speed of vehicles. The information is collected automatically.
- **Automatic Traffic Recorders (ATR) Sites** ATRs automatically collect information by means of in-pavement loop detectors. ATRs are located throughout the State and are typically used to determine vehicle counts. A small number of them have been installed to allow the collection of speed data.
- **Portable data collection machines with road tubes, in-pavement loop detectors, or portable magnetic sensing devices.** This method of data collection requires the placement of a sensing device on the road surface which connects to the data collection machine located off the road. This method is undesirable due to manpower requirements.

6.2.8 Wrong-Way Detection

An important area of concern relative to highway safety is the occurrence of drivers going the wrong way on one-way streets, highway mainline lanes, or highway entry or exit ramps. Along with significant signing, various monitoring approaches have been tried and implemented to provide immediate detection of vehicles going the "Wrong Way". To date, systems using magnetic induction loops represent the most common solution for "Wrong Way" detection. Two or more loops are placed in the roadway as shown in Figure 11. Relative to the correct direction of travel, loop #1 is the upstream vehicle detection sensor and loop # 2 is the downstream vehicle detection sensor. In the presence of traffic, vehicle detection at loop # 1 followed by detection at loop #2 indicates the correct direction of travel by the detected vehicle. Vehicle detection at loop #2 followed by detection at loop #1 indicates the incorrect direction of travel by the detected vehicle. When properly installed and maintained, the loop-based system performance should be reasonable.
6.2.9 Detection Zone
Detection Zone (Area of Detection, Detection Area, Zone of Detection, Effective Loop Area, Field of Influence, Field of View, Sensing Zone, Footprint) is the area of the roadway within which a vehicle is detected by a sensor system.

6.2.10 Setup vs. Design Parameters
(reserved)

6.3 Closed Circuit Television (CCTV)

CCTV shall mean a video or still picture camera system used to collect images and relay images to a central monitoring location, and project images onto a video monitor, television screen, Internet display, or other monitoring equipment.

Closed circuit television (CCTV) cameras are a key part of traffic management systems. The primary benefit of CCTV is the ability to provide visual information required to make informed decisions. CCTV cameras are used for roadway traffic monitoring, verification of incidents detected by other means (e.g., cellular calls, speed detectors, etc.), and for assistance in determining appropriate responses to an unplanned event or incident. Beyond these tasks, cameras can be utilized for:

- Monitoring traffic movements on the mainline and ramps.
- Variable Message Sign verification.
- Verification of stranded motorists and incidents.
- Observing localized weather and other hazardous conditions.
- Allows dispatching of safety personnel

6.3.1 The Camera System

The camera system is a suite of components which work together to create a seamless video unit. The camera system is capable of acquiring traffic video, digitizing and transmitting the resulting data into a network infrastructure, and receiving and reacting to commands with feedback to the controlling system. Each camera site contains a full camera system and is strategically located adjacent to a route to best acquire traffic video. The video system consists of a camera, pan-tilt-zoom (PTZ) assembly and camera control receiver (CCR).
Both analog and digital cameras are marketed for freeway management application, as summarized below. Transmission of analog video requires large amounts of bandwidth. For transmission distances of more than 500 feet, analog video must usually travel over coaxial cable or fiber optic cable.

- **Analog.** The main component for analog cameras is the Charge Coupled Device (CCD) sensor. The CCD sensor is a solid-state imaging technology available in a compact, inexpensive format. CCD cameras are typically available in a variety of imager size formats, including 2/3", 1/2", 1/3" and 1/4". The two most common, proven CCTV camera sensors are the interline transfer and frame transfer CCDs. Both CCD devices provide good quality video and good sensitivity.

- **Interline CCD** is the most commonly used system type for security and surveillance applications in traffic management, mass transit, airports, and military applications. Interline CCD sensors are smaller than frame transfer imagers, have longer service life, require less periodic maintenance, produce no geometric distortion, are immune to vibration, magnetic fields and direct exposure to sunlight or headlight, and consume minimal power. The interline transfer CCD image device eliminates overload streaking because it is not sensitive to infra-red, improves dynamic range, and also provides high resolution.

- **Digital.** An alternative to analog video technology is Digital Signal Processing (DSP). Digital video requires that the analog video source be converted to digital "data". This is accomplished via a CODEC (coder-decoder). The process is very similar to the conversion of voice from analog to digital, but is substantially more complex. Several different types of video CODECs are available to serve a wide variety of communication needs. The CODEC provides two functions. First, it converts the analog video to a digital code. Second, it "compresses" the digital information to reduce the amount of bandwidth required for transmission. In the process of converting from analog to digital and back to analog, the video image loses some quality. The compression process also adds a small loss of video quality. Each of the following CODECs has its own set of video image quality loss characteristics.

**Night Time Considerations:** An IR Cut Filter is an extra filter inside the camera that moves behind the camera lens when it gets dark. A camera with an IR Cut Filter will produce very high quality images in low light conditions.

**Dome Camera:** MnDOT TMC no longer uses the dome style camera. One issue is camera icing. Also, there is a blind spot with the domes due to the mounting.

For arterial operation, CCTV can be used to fine tune signal timing.

### 6.3.2 CCTV Mounting

For fixed location CCTV systems, video cameras are permanently mounted either on existing structures along the freeway or on specially installed camera poles.
Mounting Heights
A MnDOT CCTV is typically mounted on a 50’ high folding pole. Details can be found at:
http://www.dot.state.mn.us/products/tms-its/CCTVMaterials.html

Field of View
Current CCTV technology allows viewing of ¼ to ½ mi (0.4 to 0.8 km) in each direction if the camera mounting, topography, road configuration, and weather are ideal. The location for CCTV cameras is dependent on the terrain, number of horizontal and vertical curves, desire to monitor weaving areas, identification of high-incident locations, and the need to view ramps and arterial streets. Each prospective site must be investigated to establish the camera range and field-of-view that will be obtained as a function of mounting height and lens selection.

Crankdown Pole
A MnDOT CCTV is typically mounted on a 50’ high folding pole. Details can be found at:
http://www.dot.state.mn.us/products/tms-its/CCTVMaterials.html

Required Wind loads
The current MnDOT design shall endure a wind velocity of 80mph.

Existing Structures
(reserved)

6.3.3 Performance and Bandwidth
This is an issue if you do not have a high bandwidth connection to the camera. For example, in some remote rural areas the camera may be using a wireless link with much less bandwidth than a fiber optic connection. In cases of limited bandwidth, you have to trade off things like camera resolution, refresh rate, and compression losses. You have to design the communication system to effectively allow access to the video minimizing bottleneck links. Performance also affects camera control. In a low bandwidth situation, there is a delay between issuing the camera movement command and when you actually see the camera moving, which makes it difficult to point the camera where desired. In these situations you may want to make sure that the camera control includes the ability to use presets so that the operator can easily point the camera in the desired direction.

6.3.4 Camera Control
Using a pan/tilt (P/T) platform, CCTV system operators can change camera position about the 360-degree "azimuth" axis, and adjust camera elevation up or down (within a 140 degree range). Together with a zoom lens, the P/T allows operators to view a scene within any direction about the camera, and within the lens field-of-view and distance ranges.
Figure 12 – CCTV Pole Installation Detail
6.3.5 Temporary Cameras

Portable CCTV systems can serve several purposes including the following:

- Short-term traffic monitoring in areas with non-recurring congestion (e.g., work zone, critical incident, detours etc.).
- Traffic monitoring at special traffic generators (e.g., stadiums, parades, etc.).
- Traffic monitoring along evacuation routes
- Determination of optimum camera location for fixed location CCTV systems.

Portable CCTV systems are typically mounted in a light truck or van or on a trailer. Components of a portable system include the following:

- Camera with pan-tilt-zoom capability.
- Telescopic boom.
- Television monitor and video recorder
- Camera control unit for controlling pan, tilt, and zoom functions.
- Generator for powering equipment; or battery power with solar charging
- Air compressor for operating telescopic boom.
- Wireless communications

6.3.6 Camera Housing

The camera housing is made up of the environmental enclosure and pan/tilt zoom unit, heaters, windshield washers, wipers, etc.

6.4 Dynamic Message Signs (DMS)

A dynamic- message sign, often abbreviated DMS, is an electronic traffic sign often used on roadways to give travelers information about special events. Such signs warn of traffic congestion, accidents, incidents, roadwork zones, or speed limits on a specific highway segment. In urban areas, DMS are used within parking guidance and information systems to guide drivers to available car parking spaces. They may also ask vehicles to take alternative routes, limit travel speed, warn of duration and location of the incidents or just inform of the traffic conditions.

A complete message on a panel generally includes a problem statement indicating incident, roadwork, stalled vehicle etc; a location statement indicating where the incident is located; an effect statement indicating lane closure, delay, etc and an action statement giving suggestion what to do traffic conditions ahead. These signs are also used for AMBER Alert messages.
The most critical locations for installing permanent DMSs are in advance of interchanges or highways where drivers have the opportunity to take some action in response to messages displayed on the sign. A DMS should not compete with existing roadway signs. At times, relocation of some static signs may be required in order to install a DMS at a critical location. In general, a DMS should be permanently installed at the following locations:

- Upstream from major decision points (e.g., exit ramps, freeway-to-freeway interchanges, or intersection of major routes that will allow drivers to take an alternate route).
- Upstream of bottlenecks, high-accident areas, and/or major special event facilities (e.g., stadiums, convention centers).
- Where regional information concerning weather conditions such as snow, ice, fog, wind, or dust is essential.

The ease with which a sign can be detected in the environment (conspicuity) and the ease with which the message can be read (legibility) will enhance the effectiveness of motorists' visibility of the CMS and its message. In addition, the manner in which the message is displayed must be considered (e.g., if the message is too luminous, it can be easily detected but difficult to read because of glare.) Factors that affect the legibility of light-emitting CMSs include the character height; font style; character width (spacing and size of pixels); spacing of characters, words and lines; size of sign borders; and contrast ratio.

The DMS designer and operator need to know about the actual site characteristics in the vicinity of the DMS. These characteristics dictate the amount of information that can be displayed. Among the items of interest are the following:

- The operating speed of traffic on the roadway;
- The presence and design characteristics of any vertical curves affecting sight distance;
- The presence of horizontal curves and obstructions such as trees, bridge abutments, or construction vehicles that constrain sight distance to the CMS around the curve;
- The location of the CMS relative to the position of the sun (for daytime conditions);
The presence, number, and information on static guide signs in the vicinity; and
Whether or not rain or fog is present to degrade visibility to the sign.

Other design considerations include: sign size (which affects message length as well as support structure requirements), maintenance access (e.g., walk-in housings, front access), technology, viewing angle and distance, character size, and sign position relative to sun during various times of day and days of the year.

As discussed later, the maximum length of a message that should be displayed is primarily dictated by the amount of information drivers can read and comprehend during the period when they are within the legibility distance of the DMS. The maximum length of a DMS message is also controlled by the characteristics of the sign. These include the type of sign (LED, fiberoptic, etc.), the number of lines available, and the number of characters on each line. Each of these characteristics can have an effect on how far away the DMS can be read and, consequently, how much information can be presented to motorists. It should be the responsibility of the TMC manager/supervisor to assess the DMS characteristics and determine the maximum length of message to display.

### 6.4.2 Sign Types

Most signs are based on Light Emitting Diode (LED) technology. LEDs are low power and last for a long time. Some signs can be supplemented with flashing beacons. Many signs have photocells to sense the ambient lighting conditions and adjust the brightness of the display automatically. Some signs have environmental controls in their housing, such as ventilation fans and potentially heaters. Some signs can incorporate locally generated data into the centrally controlled message, such as including the time, temperature, or speed of closest vehicle into the message on the sign. Many signs have built-in diagnostics that can notify an operations center upon failure of pixels, modules, communications, environmental controls, etc.

**Overhead Mount vs. Roadside Mount**

If you have more than 2 lanes per direction of traffic, or heavy traffic with 2 lanes per direction, the overhead mount is beneficial so that other traffic does not block the driver’s view of the sign. For 2 lane roads (one lane per direction), or for 4 lane roads with light traffic, a roadside mounted sign may be acceptable and will probably be less expensive.

**Sign Characteristics**

DMS can be character based, line matrix, or full matrix. A character based sign has a defined set of characters and can display one character per position on the sign. These signs cannot do graphics. A line matrix sign considers each line of the sign as a grid of pixels, and can display any combination of pixels on the line. This allows different fonts for text and allows for graphics. A full matrix sign considers the whole sign as one big matrix of pixels which can be controlled in any combination. This allows for even more advanced fonts, such as fonts taller than a single line of the sign, and allows for graphics.

**Pixel Colors**

Many signs have amber pixels on a black background. The MN MUTCD recommends that the color be suitable for the type of message, such as white on black for regulatory, yellow on black for warning, etc., but allows using amber for everything. High definition full color matrix signs are full matrix signs with closely spaced pixels that can be any color. This allows close replication of standard sign elements, such as an Interstate freeway route shield. Although they are capable of displaying photos and moving images, these should not be used in the highway environment.

### 6.4.3 Sign Control

Sign control allows an operator to select a message for display on a sign and to monitor and adjust other sign parameters. Sign control may be provided locally at the sign location itself or remotely from a center.
Portable Changeable Message Signs mounted on a trailer for temporary use are a common application for local sign control, such as in a work zone. A permanently mounted DMS will normally provide for remote control of the sign. The operator will want to be able to remotely determine what message is currently displayed on the sign, to put new messages on the sign, to blank out the sign, and to obtain diagnostic information on the condition of the sign. Sign control may allow an operator to adjust parameters such as brightness, temperature for cooling fans to turn on, etc.

6.5 Ramp Meters

Ramp Meters are traffic signals on highway entrance ramps, and they are designed to:

- Reduce crashes
- Reduce congestion
- Provide more reliable travel times

MnDOT Goals for Ramp Meters:

- Ramp meter waits will be no more than four minutes per vehicle on local ramps and two minutes per vehicle on freeway-to-freeway ramps.
- Vehicles waiting at meters will not back up onto adjacent roadways
- Meter operation will respond to congestion and operate only when needed.

Ramp meters may be controlled locally based on time-of-day and day-of-week, or via traffic responsive metering where metering is enacted based on volume, occupancy, or speed being obtained by the local freeway detection. Ramp meter plans are stored in the controller in the same manner as surface street intersection traffic signals. In the Twin Cities, ramp meters are centrally located.

Flashers are installed above standard "Signal Ahead" signs on high-speed ramps requiring advance warning of the metering operation. The flashers, 8-inch circular yellow indications mounted at a height of 10 feet, operate during the metering period.

6.5.1 Signal Heads and Mounting

Signal head and mountings – materials are important. Away from painted poles, etc. Figure 14 illustrates a one-way ramp control detail.
Figure 14 – Ramp Meter (One-Way) Detail

6.5.2 Control Cables
(reserved)
6.6 RWIS

A road weather information system (RWIS) is a combination of technologies that collects, transmits and disseminates weather and road condition information. The component of an RWIS that collects weather data is the environmental sensor station (ESS). An ESS is a fixed roadway location with one or more sensors measuring atmospheric, surface (i.e., pavement and soil), and/or hydrologic (i.e., water level) conditions including:

- Atmospheric sensors – air temperature, barometric pressure, relative humidity, wind speed and direction, precipitation type and rate, visibility distance
- Surface sensors – pavement temperature and condition (dry, wet, ice, freeze point, chemical concentration), subsurface temperature, subsurface freeze/thaw cycles
- Hydrologic sensors (stream, river and tide levels)

Data collected from environmental sensors in the field are stored onsite in a Remote Processing Unit (RPU) located in a cabinet. In addition to the RPU, cabinets typically house power supply and battery back-up devices. The RPU transmits environmental data to a central location via a communication system. Central RWIS hardware and software collect field data from numerous ESS, process data to support various operational applications, and display or disseminate road weather data in a format that can be easily interpreted by a user. Environmental data may be integrated into automated motorist warning systems, and transmitted to TMCs, emergency operations centers and maintenance facilities for decision support. This information may also be used to enhance forecasts and supplement mesoscale environmental monitoring networks (i.e., mesonets)

Weather service providers (who are often RWIS/ESS vendors) also use the data to develop tailored weather services and products, including pavement temperature / bridge icing forecasts, ice and snow prediction, optimization of treatment routes and resource allocation, and thermal mapping. The latter is a process to quantify the variation in nighttime road surface temperatures across the roadway network. This variation can be 10°F or greater (depending on exposure, altitude, traffic, and road materials), which can impact which areas may become icy before others.

Transportation managers utilize environmental data to implement three types of road weather management strategies – advisory, control and treatment. Advisory strategies provide information on prevailing and predicted conditions to both transportation managers and motorists. Control strategies alter the state of roadway devices to permit or restrict traffic flow and regulate roadway capacity. Treatment strategies supply resources to roadways to minimize or eliminate weather impacts. Many treatment strategies involve coordination of traffic, maintenance, and emergency management agencies. Winter maintenance managers utilize road weather information to assess the nature and magnitude of threats, make staffing decisions, plan treatment strategies, minimize costs (i.e., labor, equipment, materials), and assess the effectiveness of treatment activities (by agency staff or subcontractors). Traffic managers may alter ramp metering rates, modify incident detection algorithms, vary speed limits, restrict access to designated routes, lanes or vehicle types (e.g., tractor-trailers) and disseminate road weather information to motorists in order to influence their travel decisions. Some Traffic Management Centers integrate weather data with traffic monitoring and control software. Emergency managers may employ decision support systems that integrate weather observations and forecasts with population data, topographic data, as well as road network and traffic data. When faced with flooding, tornadoes, hurricanes, or wild fires; emergency managers may use this data to evacuate vulnerable residents, close threatened roadways and bridges, and disseminate information to the public.

Note: RWIS uses a different key than other cabinets.
6.7 Dynamic Warning Flashers

Examples include a “crossing traffic ahead” sign activated by a detector at a stop line on a stop controlled approach, a curve warning flasher that activates if a vehicle is approaching a curve above a certain speed threshold, an over height detector with a warning flasher, a fog warning with flasher, an activated animal warning system (deer crossing), etc. In all the cases, there is some means of detection that then activates a flasher on a warning sign. These would normally have the sign mounted to a traffic signal pedestal with breakaway base and a flasher on top or wig-wag flashers on either side of the diamond shaped warning sign.

Configuration should not mount a heavy cabinet on the side of the pedestal pole where it could be a problem if the pole gets hit.

6.7.1 Flashing Beacons

The flashers for a dynamic warning flasher should be standard LED signal sections, red or yellow as appropriate, 8 inch or 12 inch as appropriate. Yellow beacons are required for use with warning signs. A red beacon is used with a STOP sign. Single beacons on a high speed road should be 12 inch. Beacons on a low speed road or used as a pair in a wig-wag configuration should be 8 inch. All beacons should have background shields. As per the MN MUTCD, the beacon should be mounted at least 12 inches from the edge of the sign.

6.7.2 Flasher Cabinet

When the flasher pedestal is located on a high speed road using breakaway mounting, the flasher cabinet should not normally be mounted to the pedestal, as it could come off on impact and become a projectile. A separate cabinet mounted outside the clear zone can house the flasher, circuit breaker, any sensor electronics used to activate the flasher, and any control or communications equipment.

6.7.3 Activation

Depending upon the application, the flasher may be activated by a sensor and/or a controller. Sensors may include speed sensors, vehicle presence sensors, or height sensors, for example.

6.8 Highway Advisory Radio (HAR)

Highway Advisory Radio (HAR) refers to low power AM or FM radio transmissions where localized information is broadcast and travelers are alerted to the presence of the broadcast using static or dynamic signs. The localized transmissions may cover areas that range from 5 miles to 30 miles depending upon the terrain and technologies used. The radio transmissions may be either at fixed permanent locations or mobile devices that may be temporarily located and moved as needed.

6.8.1 Field System

The transmitters and other broadcast components are located in the field. There are multiple technologies available for HAR application.

10-Watt AM Transmission (FCC Licensed)

This is the most common HAR application. When properly maintained and installed, 10-watt transmitters have a broadcast radius of approximately 3–5 miles depending on topography, atmospheric conditions, and the time of day. Frequencies used are generally located at the extreme ends of the AM band using specific frequencies based upon the availability of "holes" in the spectrum left by government and commercial stations. New FCC rules permit HAR to be broadcast on any frequency between 530 kHz and 1710 kHz provided an FCC license is obtained. The FCC rulings have also opened up the former dedicated HAR
frequencies, 530 kHz and 1610 kHz, to commercial broadcasting, thereby increasing the potential for interference or possibly the loss of a license.

The characteristics of the broadcast are also affected by the frequency used. The lower ranges of the band (e.g., 530 kHz) are adversely affected by power lines (because of its long wavelength). It also has problems with signal fade, which causes distorted transmission for a reasonable distance along the outer (fringe) areas of the coverage area. Because of this, it is uncommon to find any commercial broadcasters on this end, which is an advantage. On the other end of the spectrum, power lines have less impact on the signal, and a crisper fringe transmission.

**Digital Highway Advisory Radio**

Digital HAR eliminates many limitations of traditional dial-up systems, and improve quality of messages being broadcast to the traveling public. While dial-up systems typically operate over analog phone lines, advanced computer-controlled systems use digital signal processing to optimize performance.

Compared to traditional dial-up systems, "digital HAR" offers increased speed of message updating, centralized management of multiple stations, enhanced reliability, superior audio quality, ease of operation, and automated event logging. The time required for an operator to update audio at a remote site from the central control unit can be as little as two seconds. This can be accomplished through a simple "drag & drop" operation using a specialized Windows program. A Windows environment also easily allows for control of multiple HAR stations from a single central location.

Digital control provides closed loop operation assuring that messages and commands are received exactly as downloaded. There is no guessing about what is occurring at the remote sites. Analog phone lines typically limit audio bandwidth to about 2.5 kHz reducing the quality of the audio motorists receive on their vehicle radios. If desired, digital messages can be downloaded to remote HAR sites at CD quality provided that FCC imposed bandwidth limitations are satisfied.

**Low-Power AM Transmission (No FCC License Required)**

Low-power HAR has been developed as a means of tightly controlling the broadcast zone and thereby limiting interference from adjacent zones. Low power HAR differs from the previously discussed 10-watt HAR in that its broadcast radius (per transmitter) is generally limited to 500 feet to 1500 feet. By FCC regulation, each transmitter is limited to a maximum 0.1 watt power input to the final frequency stage, and the total length of the transmission line, antenna, and ground lead cannot exceed 3 meters. Whereas this limits its broadcast range, it also provides for a reasonably well-defined area of influence, which, through an inter-connection and synchronizing process, permits upwards of 100 transmitters to be coordinated into larger and well-defined saturation zones. Once a car leaves this broadcast area, the signal quality becomes too weak to be heard. This permits a second zonal configuration to be established nearby, transmitting a different message on the same frequency.

By using this concept, a series of zones all operating on the same frequency, may be established whereby unique site-specific messages may be transmitted to provide condition updates in advance of decision points. Aside from the flexibility provided in establishing multiple message zones, low-power HAR may also broadcast over any available AM radio frequency without the need to obtain additional FCC licensing approval. Though the ability to install a system without FCC approval provides the user with great flexibility in installing a system wherever desired, there is no guarantee that once installed, it will not be interfered with by some future more powerful transmission.

The relatively low signal strength must compete with a variety of obstacles, including overpowering commercial broadcasts, signal skip (particularly at night), and poor signal propagation. These difficulties can
be overcome by saturating an area (zone) with multiple transmitters and synchronizing their broadcasts. However, this concept is relatively new and, very expensive as the number of transmitters required is large.

**Low-Power FM Transmission (FCC License Required)**

LPFM service is available to noncommercial educational entities and Travelers’ Information Station entities, but not commercial operations or individuals. Maximum effective radiated power for these stations is 100 watts, and the LPFM stations will not be protected from interference caused by full service stations that make changes to their operations. A construction permit or license is required before construction or operation of a LPFM station can be initiated.

Low-power 100-watt FM transmitters, when installed properly, have a broadcast radius of approximately 3-5 miles depending on topography and atmospheric conditions. 10-watt transmitters have an effective range of 1-2 miles in radius. At present, LPFM licenses are not being issued for HAR. The FCC only opened the application process for frequencies for a short time period. The FCC is non-committal about if and when this technology will again be available for HAR.

### 6.9 Electrically Operated Gates

Examples of electronically operated gates include:

- Interstate and non-interstate snow and ice closure gates
- Interstate 394 gate for reversible HOV
- At transit stations to control transit flow

Battery backup may be used for electronically operated gates.

### 6.10 Intelligent Work Zones

The following handout is from:

Minnesota IWZ Toolbox

Guideline for Intelligent Work Zone System Selection

Written, compiled and illustrated by the Minnesota Department of Transportation Office of Traffic, Safety, and Operations

MINNESOTA INTELLIGENT WORK ZONE TOOLBOX
2008 EDITION
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Introduction:

The IWZ Toolbox has been prepared as a guideline for selecting an appropriate Intelligent Work Zone (IWZ) System for existing work zone traffic issues and to mitigate anticipated issues on scheduled projects. The IWZ System descriptions contained in this toolbox are intended as brainstorming material and should lead to practical solutions to a project's unique problems. The examples are purposely left void of many dimensions, except where particular distances are highly recommended, and engineering judgement is required to customize the system to a project.

IWZ Systems may be sorted into 3 category types based upon detectable stimuli: "Traffic", "Vehicle", and "Environmental". The 3 categories are shown below with their typically associated systems:

**Traffic Responsive Systems** collect and respond to average traffic characteristics such as speed and volume of a group of vehicles and the systems react to trends of increasing/decreasing values. The combination of these basic systems form the basis for Route Management Systems (or Traveler Information Systems) by analyzing and reporting information in various ways. These applications may include:

- Travel Time Information (Trip Time or Estimated Delay)
- Speed Advisory Information
- Congestion Advisory
- Stopped Traffic Advisory
- Dynamic Merge (Late or Early)
- Traffic Responsive Temporary Signals
- Temporary Ramp Metering

**Vehicle Responsive Systems** collect and respond to individual vehicle characteristics such as speed, dimensions, and location. When adverse conditions are detected by these systems, motorist need immediate warnings for quick response. These applications may include:

- Excessive Speed Warning (including Dynamic Speed Display Signs)
- Over Dimension Warning
- Work Space / Haul Road Intrusion Warning
- Construction Vehicle Warnings

**Environmentally Responsive Systems** collect and respond to changing non-traffic conditions of weather, roadway or working characteristics such as visibility conditions or roadway surface conditions and hazards. These applications may include:

- Hazardous Condition Warnings (Flooding, Ice, Fog, Smoke, Dust, etc.)

The real-time data collected for any of these systems may be combined, averaged, analyzed for trends, and utilized for several informational uses. For example, data collected for 'Stopped Traffic Warnings' may be to control a 'Dynamic Merge' system or to calculate 'Travel Time' through a corridor.

Temporary Traffic Control Devices may be equipped with advanced communication and/or remote control capabilities which that do not react "intelligently" to detectable field data, but the devices provide safer working conditions or improve incident response. Although these devices may not be "Intelligent", they have been included in the IWZ Toolbox as additional safety tools for consideration when an IWZ System is being deployed. These applications may include:

- Changeable Work Zone Signage (WZ Speed Limit Signs)
- Traffic Surveillance Cameras
**Typical System Components:**
Each IWZ System in the Toolbox is a collection of standard system components which have been combined to produce a useful real-time system. The individual component functions include the collection of data, verifying the accuracy of the data, transmitting the data, storing and managing the data, analyzing the data, and/or providing the data to the motorist.

**Detection Components:** The detectors may include:
- Radar
- Pneumatic Road Tubes
- Light Beams
- Acoustical
- Ultrasonic
- Magnetic
- Piezo-Electric
- Video
- RFID
- Probe Injection Technologies, etc.

**System Analysis Components:** analysis algorithms are designed or modified for each application of an IWZ System to fit the conditions of the project. Algorithms can be designed with apparent limitations and strengths, and field testing is necessary to ensure the quality of the data analysis.

**Data Management Components:** the storage of data and analysis of the data for various trends, events, etc. may utilize many different database systems.

**Dynamic Informational Components:** dynamic components provide information to the motorists and may include:
- 511 Systems (internet & phone/cell phone),
- Changeable message signs (CMS) in dynamic mode,
- Static signs with dynamic features,
- Remotely activated traffic control devices,
- Audible or visual alarms,
- Real-time highway advisory radio (HAR),
- Public media announcements,
- CB Radio, etc.

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**Supplementing Existing System Components:**
Mn/DOT, through it’s Regional Transportation Management Center (RTMC) and out-state TOCC’s, has the capability to provide a variety of IWZ Systems for Mn/DOT construction and maintenance projects. However, Mn/DOT’s detection devices, communications networks or traveler information systems may not be adequate for a proposed IWZ System. Discrepancies may be due to construction interrupting permanent installations, or that the existing system components do not extend to the project area.

IWZ System components provided by a contractor would supplement the services of the RTMC or TOCC’s, when various devices/services are not currently available and may include any of the component types listed above.
DEFINITIONS FOR USE IN THIS DOCUMENT

- **Changeable Message Sign (CMS):** A sign that is capable of displaying more than one message, changeable manually, by remote control, or by automatic control. The device is considered "portable" when trailer mounted. The device may be operated in one of two modes:
  - **Standard Mode:** Message is programmed to remain displayed until changed by the operator or via a timer.
  - **Dynamic Mode:** The message is programmed to respond to traffic operating characteristics or roadway conditions.

- **Static Sign:** A message for the motorist is printed on a standard sign, either regulatory, warning or guide signs.

- **Advisory Speed:** A recommended speed for vehicles based on the current roadway conditions or operating characteristics. Advisory Speeds are not enforceable.

- **Speed Limit:** The speed applicable to a section of highway as established by law.

- **Travel Time:** The estimated amount of drive time from the motorist's current location to an identified location, generally limited to approx 10 miles maximum distance.

- **Travel Delay:** The estimated amount of extra time the motorist will incur due to traffic conditions in a work zone located downstream. Generally useful for spot locations at a great distance away from the motorist's current location, which provides alternate route possibilities.

- **Devices (components):** The individual parts or subsystems that makeup a working IWZ System. Examples include: cameras, various detectors, signs, data monitoring or recording equipment, communication systems, TTC devices, and remotely activated alarms, etc.

- **IWZ System:** An automated system of devices that provides motorists and/or workers real-time information for improved safety and mobility through a work zone. The devices are integrated to monitor traffic operating characteristics or roadway conditions and react with a predetermined response.

- **Warrants:** Conditions which should be satisfied before considering an IWZ system for deployment as part of a project's temporary traffic control plan.

- **Benefits:** Anticipated affects mobility and safety when the system is properly designed and deployed. Mobility and safety measures may be within the work zone or surrounding network, and may include the public, the workers, or the constructability of the project.

- **Options:** Various options may be available for portions of the IWZ Systems. The options should be considered when they achieve satisfactory results with lower levels of 'system complication' and cost.

SYMBOLS USED IN IWZ TOOLBOX ILLUSTRATIONS

- **Changeable Message Sign (CMS):** Roadside location symbol shown on left with an example of two alternating messages shown on right.

- **Static Guide Sign:** Roadside location symbol shown on left with example message shown on right.

- **Static Guide Sign with CMS Characters:** Roadside location symbol shown on left with example message shown on right.

- **Dynamic Flashing Warning Sign:** Roadside location symbol shown on left with example message shown on right.

- **Non-Intrusive Detection Device:** The symbol denotes any type of detection device(s) and the actual location and number of devices will vary from the toolbox illustration.

- **Advance Warning Sign:** Roadside location symbol shown on left with example message shown on right.

- **Temporary Traffic Control (TTC) Device:** The symbols denote standard TTC devices as defined by the MN MUTCD and the Field Manual of TTC Layouts. To highlight the IWZ systems, only a minimal amount of TTC devices have been shown on the toolbox illustrations. Key devices shown may include standard warning signs, Type III barricades, channelizing devices and flashing arrow panels.

GENERAL IWZ TOOLBOX NOTES

- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.

- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.

- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.

- Refer to the Toolbox Definitions Section for graphic symbols and terms.

- Toolbox Illustrations are NOT Drawn to Scale.
IWZ SYSTEMS LISTED IN THIS PUBLICATION

- Travel Time Information - Trip Time or Estimated Delay
- Speed Advisory Information
- Congestion Advisory
- Stopped Traffic Advisory
- Dynamic Merge - Late or Early
- Traffic Responsive Temporary Signals
- Temporary Ramp Metering
- Excessive Speed Warning - incl. Dynamic Speed Display Signs
- Over Dimension Warning
- Work Space / Haul Road Intrusion Warning
- Construction Vehicle Warnings - Merging, Crossing & Exiting
- Hazardous Condition Warnings - Road Surface or Visibility
- Changeable Work Zone Signage - incl. WZ Speed Limits
- Traffic Surveillance Camera

Note: The IWZ Toolbox Sheets contained within this document are preliminary illustrations and may not accurately represent all the IWZ Systems as typically deployed.

The systems may be combined, modified, enhanced or simplified as necessary for a particular project. Please use these toolbox sheets to brainstorm IWZ possibilities, and consider what conditions may be needed to make the application viable. When a system is deployed, we hope to quantify these conditions further, with refined warrants on the system's toolbox sheet. We also wish to quantify benefits derived from the deployments where ever possible in addition to the intuitive benefits that may be reaped from the IWZ systems.
### WARRANTS
- The work zone may cause 15 minutes or more of additional travel time.
- The work zone causing the delay is within 10 miles of the CMS location.

### BENEFITS
- The system should inform the drivers what the estimated travel time is between their current location and a specific destination beyond them (up to 10 miles maximum).
- The system will give drivers information which will allow them to decide whether to change routes, provide them opportunity to notify others of their estimated arrival time, and generally provide drivers sufficient information to calm tempers.

### OPTIONS
- The CMS may be replaced with static warning signs equipped with two (2) CMS characters in dynamic mode. The characters would display the real-time travel time in the work zone downstream.
- Consideration should be given to posting an alternate route and travel time for additional driver information.
- The CMS may be supplemented with other informational devices such as Highway Advisory Radio (HAR).

### NOTES
- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.
- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.
- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.
- Refer to the Toolbox Definitions Section for graphic symbols and terms.
**WARRANTS**

- The work zone may cause 15 minutes or more of additional travel time.
- The work zone causing the delay is located more than 10 miles beyond the CMS location (preferably 25 to 50 miles or more, such that multiple alternate routes are available).

**BENEFITS**

- System should inform the drivers what the estimated delay time is at an approximate location along the roadway downstream. The delay is calculated based upon queue speeds vs. normal travel speeds.
- The system will give drivers information which will allow them to decide whether to change routes, provide them opportunity to notify others of their estimated arrival time, and generally provides drivers sufficient information to calm tempers when they arrive at the cause of the delay.

**OPTIONS**

- The CMS may be replaced with static warning signs equipped with two (2) CMS characters in dynamic mode. The characters would display the real-time travel delay in the work zone downstream.
- Consideration should be given to posting an alternate route and travel time for additional driver information.
- The system may be converted to a Travel Time system within 10 miles of the destination location (such as Hwy CC in this example).
- The CMS may be supplemented with other informational devices such as Highway Advisory Radio (HAR).

**NOTES**

- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.
- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.
- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.
- Refer to the Toolbox Definitions Section for graphic symbols and terms.
**WARRANTS**
- The work zone will cause additional travel time.
- The work zone queue is estimated to slow traffic at least 20 mph below the posted speed limit.

**BENEFITS**
- The system should advise drivers of an appropriate vehicle speed to allow them to travel through the work zone with minimal braking.
- The system will smooth the transition between faster and slower moving traffic.
- The system should provide an increase in capacity of the roadway through the work zone area.

**NOTES**
- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.
- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.
- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.
- Refer to the Toolbox Definitions Section for graphic symbols and terms.

**OPTIONS**
- The CMS may be replaced with static warning signs equipped with two (2) CMS characters in dynamic mode. The characters would display the real-time average speed in the work zone downstream.

**OPTIONAL DESIGN:** combination of static sign and digital number display

The CMS should be located 2 - 3 miles before the slow traffic queue. The displayed speed is the average speed detected entering the work zone location. Based on this information, the motorist may adjust speed to anticipate the slower traffic.

The system should provide an increase in capacity of the roadway through the work zone area.
WARRANTS

- Queue lengths are estimated to vary greatly, day-by-day and hour-by-hour such that a suitable location for the TTC advance warning signage can not be predicted. Note: signs placed more than a mile ahead of confirmation are typically forgotten by the motorist.

- Queue lengths may encroach upstream beyond a motorist's reasonable expectations for stopped traffic and there is probability that the geometrics (terrain) may cause poor visibility of end of traffic queues, causing short reaction times and panic stopping.

- The queue is estimated to stop downstream of the last CMS in the system.

BENEFITS

- The system should alert drivers of an upcoming traffic slow-down or stopped traffic, providing time to determine possible route alternates, and to be prepared to stop safely.

- Traffic may divert to alternate routes.

OPERATIONAL NOTES:

- When no queue is detected, all the CMS should be blank unless used for another IWZ system.

- When the queue approaches within one mile of any CMS, the CMS should operate as a "Stopped Traffic Advisory" device.

- When the queue extends beyond any CMS location, the CMS should be blank, or it may be utilized for another IWZ system such as DLM.

Options

- When queue lengths are estimated to never extend to the CMS location, the CMS may be replaced with a static warning sign equipped with two dynamic CMS characters for mileage. When no queues are detected, the mileage display would correspond with the accompanying guide sign for "Road Work XX Mi Ahead".

- When traffic queue lengths are reasonably predictable, warning motorists of stopped / slowed traffic may be accomplished with the use of typical TTC warning signs placed prior to the anticipated beginning of queue.

- The system may be combined with "Dynamic Merge", "Stopped Traffic Warning" and "Travel Time and/or Delay" systems.

NOTES

- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.

- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.

- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.

- Refer to the Toolbox Definitions Section for graphic symbols and terms.
WARRANTS

- Queue lengths are estimated to vary greatly, day-by-day and hour-by-hour such that a suitable location for the TTC advance warning signage can not be predicted. Note: signs placed more than a mile ahead of confirmation are typically forgotten by the motorist.

- Queue lengths may encroach upstream beyond a motorist's reasonable expectations for stopped traffic and there is probability that the geometrics (terrain) may cause poor visibility of end of traffic queues, causing short reaction times and panic stopping.

- Queues initiated on crossroads are estimated to cause traffic conflicts and/or delays on the mainline road, such as backups beyond the length of ramps, through or around turns in intersections, or other hazardous congestion situations.

BENEFITS

- The system should alert drivers of an upcoming traffic slow-down or stopped traffic, providing time to determine possible route alternates, and to be prepared to stop safely.

- It is anticipated that the system will reduce rear-end crashes.

- Traffic may divert to alternate routes.

OPTIONS

- The CMS may be replaced with an appropriate warning sign equipped with dynamically automated flashing lights as shown below.

- The static signs are spaced incrementally and the individual flashers are activated in response to queued traffic when the queue is detected within one mile of the sign location.

- When traffic queue lengths are reasonably predictable, warning motorists of stopped / slowed traffic may be accomplished with the use of typical TTC warning signs placed prior to the anticipated beginning of queue.

- The system may be combined with "Dynamic Merge" and "Stopped Traffic Advisory" systems

NOTES

- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.

- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.

- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.

- Refer to the Toolbox Definitions Section for graphic symbols and terms.
Two lanes of must merge into one direction will be closed to traffic and traffic must merge.

Although queues may develop at low volumes for many reasons, typically, the volume must exceed 1500 vehicles/hour to sustain a queue that was caused by merging lanes.

Estimated queue lengths may encroach beyond an upstream intersection or interchange operations.

The speeds and lane occupancy volumes are anticipated to vary unpredictably causing the motorist to have trouble identifying the best lane usage practice, such as using both lanes versus moving into the continuous thru-lane.

The system should alert drivers of an upcoming traffic slow-down or stopped traffic, and inform them to use both lanes until the designated merge point.

It is anticipated that the system will reduce the length of the upstream queue by 40%, which may reduce conflicts at nearby intersections.

By utilizing both traffic lanes, the differential speed between lanes is greatly reduced since both lanes travel at approx the same speed.

Motorists are given positive directions on lane usage and merging which clears misunderstandings between drivers and reduces road rage.

The dynamic system may be combined with Congestion Warning and Travel Time and/or Delay Systems.

When the speeds and lane occupancy volumes are anticipated to increase very predictably and hold at that a high level, the motorist should have little trouble identifying when the traffic is congesting and begin to follow the posted merging procedure, such as using both lanes. Only clear directions on proper actions are needed by the motorist. Two options:

- The directions may be supplied on static guide signs posted beyond the anticipated queue length and repeated within the queue area. An example series of Static Signs is shown below:

- When the congestion time is highly predictable, the directions may be posted on CMS as shown in the illustration, and activated by timers, rather that traffic conditions.

When traffic queue lengths are reasonably low and predictable, instructing motorists of proper lane usage may be accomplished with the use of typical TTC warning signs placed prior to the anticipated beginning of queue.

Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.

All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.

Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.

Refer to the Toolbox Definitions Section for graphic symbols and terms.
WARRANTS

SHEET UNDER DEVELOPMENT

BENEFITS

NOTES

- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.

- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.

- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.

- Refer to the Toolbox Definitions Section for graphic symbols and terms.
NOTES

- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.

- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.

- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.

- Refer to the Toolbox Definitions Section for graphic symbols and terms.
Non-Intrusive Detection spaced along the route as needed for proper system operations. Detection measures speed/capacity of traffic and determines the cycle length for the ramp meters.

Temporary pedestal mounted traffic signals. Green alternates between the two signal heads, requiring the two lanes to take turns.

Traffic forms two lanes, allowing the total queue length to be reduced.

Advance notification of change in traffic control may be used.

NOTES
- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the Mn/MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.
- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.
- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.
- Refer to the Toolbox Definitions Section for graphic symbols and terms.
WARRANTS
- Traffic must reduce speed to safety negotiate a hazardous condition such as a temporary unusually tight curve, or a rough road surface.
- Buffer spaces and/or clear-zones should be analyzed for possible intrusions by vehicles unable to sufficiently slow down in time.

BENEFITS
- System should alert a driver that they have inadvertently entered a portion of the work zone at a speed substantially above the advisory speed limit.
- The system provides sufficient time to slow down for the hazardous condition.

Example shows a reduced advisory speed limit due to sharp curve with either a substandard clear zone or inadequate buffer zone for errant vehicles.

Non-Intrusive Detection placed along the roadway as needed for proper system operations.

NOTES
- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.
- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.
- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.
- Refer to the Toolbox Definitions Section for graphic symbols and terms.
**WARRANTS**
- Workers will be located adjacent to the open traffic lane, or
- Hazardous roadway conditions require extra driving precautions.

**BENEFITS**
- The system should alert a driver of their current speed and what the advisory speed is posted for the situation.
- The system will alert drivers of their speed and provide sufficient time to slow before passing workers or entering a hazardous roadway condition.

**MINIMUM SPECIFICATIONS**
**on DSD SIGN EQUIPMENT:**

Display size of the DSD sign is dependent on the size of the speed plaque used.

<table>
<thead>
<tr>
<th>Plaque size</th>
<th>DSD display MIN.</th>
</tr>
</thead>
<tbody>
<tr>
<td>18&quot; X 18&quot;</td>
<td>10&quot; character</td>
</tr>
<tr>
<td>24&quot; X 24&quot;</td>
<td>10&quot;</td>
</tr>
<tr>
<td>30&quot; X 30&quot;</td>
<td>14&quot; character</td>
</tr>
<tr>
<td>36&quot; X 36&quot;</td>
<td>14&quot;</td>
</tr>
</tbody>
</table>

The static sign (YOUR SPEED) should be black letters on a fluorescent orange background when used with a work zone advisory speed plaque. The font should be a minimum of 4” high when used with a 10” display character, and 6” when used with a 14” or greater character display sign.

**OPERATIONAL GUIDELINES:**

The DSD sign should remain blank when no traffic is detected. When traffic speed is detected over the advisory speed plaque, the sign should blink at 50-60 cycles/minute. For speeds detected over a set max speed (generally 10 mph over the posted limit on low speed roadways and 20 mph over on high speed roadways) the display should go blank.

**NOTES**
- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.
- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.
- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.
- Refer to the Toolbox Definitions Section for graphic symbols and terms.
WARRANTS
- Construction causes temporary minimal clearance (or less than minimum) for large vehicles using the roadway, or
- A minimal clearance condition exists within a work zone and construction vehicles must be warned of the condition.

BENEFITS
- The system should alert a driver that their vehicle is over-dimension and they are required to use an escape route.
- The system should alert drivers of their route mistake and provide sufficient time to conduct the escape maneuver.
- The second portion of the system warns a driver to stop if he failed to use the designated escape route.

NOTES
- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.
- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.
- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.
- Refer to the Toolbox Definitions Section for graphic symbols and terms.

OPTIONS
- A siren or horn alarm may be included to warn workers of a vehicle intrusion
- A siren or horn alarm may be included to warn the vehicle driver
- Non-Intrusive Detection placed to determine whether an over-dimension vehicle missed the exit.
- Non-Intrusive Detection placed along the roadway as needed to measure for over-dimension vehicles.
- A siren or horn alarm may be included to warn the vehicle driver
- Non-Intrusive Detection placed to determine whether an over-dimension vehicle missed the exit.
WARRANTS

WORK SPACE INTRUSION:
- Vehicles inadvertently fail to follow standard flagging operations.

HAUL ROAD INTRUSION:
- Vehicles inadvertently follow a truck off the roadway.
  Reasons for following may vary:
  - High roadway volume causing tailgating
  - Truck exit is difficult to identify

BENEFITS

- The systems should alert a driver that they have inadvertently followed a construction truck into the construction zone or intruded into a work space.
- A work space intrusion system should alert a workers that a vehicle has intruded into the work zone.
- The systems should provide sufficient time for the driver to react appropriately, such as utilize an escape route back to the roadway traffic.

Layouts are NOT drawn to scale.

OPTIONS

WORK SPACE INTRUSION

Detection may include radio control devices operated by the flagger.

BUFFER

WORK SPACE

A siren or horn alarm may be included to warn workers of a vehicle intrusion.

DECELERATION AREA (currently not required in a work zone layout)

Deceleration distance should be based upon reaction time and braking distances.

CMS may be blank or used for another ITS function until needed.

HAUL ROAD INTRUSION

Non-Intrusive Detection placed near truck exit lane as needed for proper system operations. The detection may include radio control devices operated by the truck drivers.

CMS may be blank or used for another ITS function until needed.

Display/alarms activated by truck driver

NOTES

- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.
- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.
- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.
- Refer to the Toolbox Definitions Section for graphic symbols and terms.
**WARRANTS**
- The trucks must utilize the mainline roadway to accelerate.
- A truck merge lane can not be provided on the project.
- The haul road entrance is visibly obscured to drivers.
- The ADT on the roadway is above the level where truck drivers can easily find a gap in traffic and accelerate within the traffic lane without causing traffic to suddenly adjust speed or change lanes.

**BENEFITS**
- The system should alert drivers of a slowly accelerating truck entering the faster moving traffic lane.
- The system should provide sufficient time for drivers to react appropriately, such as slowing down or changing lanes.

**OPTIONS**
- A variation of this system may be used to detect work vehicles in the vicinity which may create a traffic hazard. The example shown below warned the motorists when snow plows were clearing the roadway in a restricted section. The signs were activated by radio communications from the plow trucks.

**NOTES**
- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.
- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.
- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.
- Refer to the Toolbox Definitions Section for graphic symbols and terms.

**VEHICLE RESPONSIVE**

**TRUCKS MERGING TRAFFIC WARNING**

**Last Revision Date:** 04-29-08
**Warrants**
- The ADT on the roadway is above the level where truck drivers can easily recognize a gap in traffic and safety cross without causing conflicts with traffic.

**Benefits**
- The system should alert drivers of a slowly accelerating truck crossing the traffic lane.
- The system should provide drivers sufficient time to react appropriately, such as slowing down.

**Options**
- When higher ADT conditions exist such that trucks are not able to find a gap in traffic, then additional traffic control systems, such as flaggers, stop signs or temporary signals, should be utilized to slow or stop traffic.
- The CMS may be replaced with an appropriate warning sign equipped with dynamically automated flashing lights as shown below and on scenario D.

**Notes**
- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.
- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.
- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.
- Refer to the Toolbox Definitions Section for graphic symbols and terms.
### WARRANTS
- The trucks must utilize the mainline roadway to de-accelerate, and
- The roadway volume is above the level where the traffic must suddenly adjust speed or change lanes.

### BENEFITS
- The system should alert drivers of a decelerating truck exiting the faster moving traffic lane.
- The system should provide drivers sufficient time to react appropriately, such as slow down or change lanes if possible.

### OPTIONS

#### Scenario G. Dedicated Lane

Typically, IWZ Systems are not needed for construction traffic is this scenario.

#### Scenario H. De-acceleration Lane

Typically, IWZ Systems are not needed for construction traffic is this scenario.

#### Scenario I. No De-acceleration Lane

Non-Intrusive Detection placed along the roadway as needed for proper system operations. The detection may include radio control devices operated by the truck drivers.

### NOTES
- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.
- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.
- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.
- Refer to the Toolbox Definitions Section for graphic symbols and terms.
WARRANTS
- The system should be considered for deployment as part of a project’s temporary traffic control plan when a temporary situation may cause a hazardous driving condition such as:
  - Flash flooding
  - Visibility (fog, smoke)
  - Slippery or rough conditions
  - Hazards on roadway (falling rock, debris)

BENEFITS
- The system should alert traffic of a hazardous condition on the roadway ahead and advise traffic of an appropriate action for the situation which may range from stopping, slowing, or diverting traffic.
- The system should notify construction staff of the situation such that corrective actions may begin.

NOTES
- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.
- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.
- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.
- Refer to the Toolbox Definitions Section for graphic symbols and terms.
**WARRANTS**
- Refer to the "Guideline for Establishing Work Zone Speed Limits" for the procedure to change speed limits.

**BENEFITS**
- The traffic control supervisor will be able to change the work zone speed limit easily without manually covering signs.

**OPTIONS**
- The CMS characters may be replaced with static regulatory speed limits printed with the appropriate speed values. The traffic control supervisor would be responsible to exchange the signs to enable the work zone speed limit to be enforceable and must return the normal posted speed limit following the approved time period. There are variations of covering the existing signs as approved alternatives to removing the signs.

---

**OPERATIONAL NOTES:**
- The static speed limit signs are equipped with 2 CMS characters that can be changed from a remote location by the traffic control supervisor for the project.
- The original posted speed limit signs shall be removed or covered while the device is activated.
- The posted speed limit value is changed to an approved enforceable 'Work Zone Speed Limit' during the designated time periods specified in the TTC plans or special provisions for the project. After the specified time period, the value of the sign is changed back to the normal posted speed for the roadway.
- For example, the time period may be based upon the presence of workers, or high volume of construction traffic.
- The traffic control supervisor shall drive through the work zone after the CMS display change to verify the correct value is displayed.

**NOTES**
- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.
- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.
- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.
- Refer to the Toolbox Definitions Section for graphic symbols and terms.

---

**CHANGEABLE WZ SPEED LIMIT SIGN**

<table>
<thead>
<tr>
<th>Warrants</th>
<th>Benefits</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refer to the &quot;Guideline for Establishing Work Zone Speed Limits&quot; for the procedure to change speed limits.</td>
<td>The traffic control supervisor will be able to change the work zone speed limit easily without manually covering signs.</td>
<td>The CMS characters may be replaced with static regulatory speed limits printed with the appropriate speed values. The traffic control supervisor would be responsible to exchange the signs to enable the work zone speed limit to be enforceable and must return the normal posted speed limit following the approved time period. There are variations of covering the existing signs as approved alternatives to removing the signs.</td>
</tr>
</tbody>
</table>
Layouts are NOT drawn to scale.

NOTES

- Advance warning signs and other standard temporary traffic control devices have not been shown on this figure. Refer to the MN MUTCD including the 2007 Field Manual or the TTC Layout Templates for typical layout examples.

- All IWZ Guide Signs and CMS should be reviewed by the Mn/DOT Office of Traffic, Safety, & Operations for design and message approval.

- Approved CMS messages should be listed in the Special Provisions, and approx CMS locations should shown on the TTC plans. All CMS displays should be blank when messages are not warranted.

- Refer to the Toolbox Definitions Section for graphic symbols and terms.
Various real-time informational methods may be deployed as required for the intended audience including:

- Real-time Highway Advisory Radio may broadcast real-time:
  - travel times on various routes between landmarks,
  - project staging information such as pending traffic changes,
  - alternate route information with congestion information, and/or
  - alternate route information with incident information.

- 511mn.org should be updated continually to have real-time travel information through the work zone. This information is available to the motorist via cell phone (and internet).

- Real-time information available online for the project's work zone and vicinity which could include information on current incidents, congestion, traffic control changes, travel delays/times or other traffic data that may be requested.

- Email notices with the current information could be generated based upon parameters pre-selected by subscribers, such as predetermined time-of-day, major incidents, major congestion, etc.
6.11 Control Cabinets

MnDOT has several types of cabinet in common use. Traffic signals use a large “R” size or smaller “P” size cabinet. The RTMC uses Type 332 cabinets based on a CalTrans design. The RTMC also has a standard CCTV control cabinet. DMS controllers and ramp meter controllers are housed in the Type 334 cabinets. The Type 334 cabinet provides 19 inch rack mounting, which works well with a lot of equipment that is used in ITS.

6.12 Power

Most ITS systems currently operate on 120 Volts AC with a power drop from the local utility company. Some systems operate using a low voltage DC power source, facilitating battery and solar power options. Some questions to consider when selecting power include:

6.12.1 Service Cabinets for Utility Power

The traffic signal service cabinet is an option for ITS systems. It has the option of adding battery backup. Large DMSs may require a higher capacity cabinet. The RTMC uses a smaller service cabinet that would cost less, without the battery backup option. For simple systems with modest power requirements, a simple meter and load center can be mounted on a pole.

6.12.2 Grounding and Surge Suppression

ITS systems usually include sensitive electronics located in an outdoor environment and mounted on metal poles. A lightning storm can cause the equipment to fail if it is not properly protected. Every control cabinet should have a quality properly rated solid state surge suppression device located where the power conductors terminate in the cabinet. In addition to the grounding required by the National Electrical Code at the service cabinet, the control cabinet should also have a grounding conductor going from its ground bus to a ground rod. The ground rod may be the one used by the service cabinet or a different one if the cabinets are not co-located. If the system includes tall mounting poles and is not connected by metal conduit, the pole installation should also include a ground rod. As per the National Electrical Code, it is essential that all metal cabinets, poles, housings, conduits, etc. all be connected together into a properly bonded and grounded system. All communications and video field cables should have surge suppression at both ends where they enter an enclosure or cabinet. Much unfortunate experience has shown that systems that are not properly grounded or protected from surges will not last long in the outdoor roadside environment.

6.12.3 Battery Backup

Part of the design for an ITS system should be consideration of failure modes. Any source of power is subject to failure. Some ITS systems are not safety critical and can tolerate the occasional power outage. For safety critical systems, battery backup is an option. Battery backup can keep the system operational for a certain period of time when utility power is out. The size of the battery backup system can be calculated based on the load drawn by the system and the length of time it must run on battery power. One consideration of battery backup is that the batteries will need to be replaced periodically, maybe every 5 or 7 years, to ensure that they can still hold a charge.
6.12.4 Solar/Wind Power

In remote rural areas, obtaining a utility power drop can be very expensive if there are no electrical utilities in the area. For some low-power ITS applications, solar and/or wind power is an option. These options are also environmentally friendly. Resources are available [provide web links] to aid in designing the solar power. Factors include the amount of power the system needs, the percent of the time the system is operating (such as flashers that only flash upon certain infrequent events), the amount of time the system must operate in the absence of any sunlight, and the geographic location which affects the amount of sunlight received. It is a good idea to overdesign the solar power system with large safety margins. Experience has seen several solar powered systems whose operation was disrupted due to inadequate solar power configurations. In Minnesota in mid-winter, hours of sunlight are limited and the cold causes the batteries to be inefficient, which makes it a challenge for solar powered systems. Wind power provides a nice complement to solar power. Cloudy times having less sunlight are often accompanied by higher winds. Wind turbines work better the higher they are mounted, and so mounting height could become a cost issue. Similar to solar power, resources are available [provide web links] to aid in designing wind powered systems. Off the shelf systems for solar and wind, including controllers, are available from multiple sources. Underground battery boxes for solar powered systems may fill with water and be ruined.

6.13 Electronic Communications

Data communications between the central server and field microprocessors are achieved in a variety of ways. Traditionally, copper cables have been used with standard modems on each end, but newer devices use a network of fiber-optic communication lines. In a few locations, leased telephone lines and wireless cameras are used.

6.13.1 Communications Standards

Communication protocols for ITS are being developed under the National Transportation Communications for ITS Protocol (NTCIP) standards development effort. These are open (non-proprietary), industry-based standards that make it possible for ITS devices from multiple vendors to exchange information — both with each other and with a central system — through a common communications interface. There are many NTCIP standards, each relating to one or more ITS applications.

6.13.2 Grounding and Surge Suppression

High quality surge suppression is very important and typically costs $350-$400 per cabinet (good grounding is critical). Without surge suppression there can be a loss of equipment.

In the past, didn’t have a ground rod on the camera pole and there were a lot of camera failures. Now, ground rods are placed and there are fewer cameras destroyed by lightning strikes. However, some argue that placing the grounding rod is creating a lightning rod.

6.13.3 Ethernet

(reserved)

6.13.4 Fiber Optic

The Fiber Optic Cable Assemblies for Fiber Optic Cable shall comply with USDA RUS CFR 1755.900 (Specification for Filled Fiber Optic Cables) and the following provisions:

- Fiber Optic Cable shall be designed for outdoor use and direct bury
- Include a dielectric central strength member.
- Armored with corrugated steel tape.
✓ Minimum of a 1.4 mm thick Medium Density Polyethylene outer jacket;
✓ Include two ripcords. One ripcord under the armor and one ripcord under the inner jacket.
✓ Outside diameter of < 23 mm (0.906 inch). G. Indented markings on one-meter (three-foot) intervals showing the manufacturer, fiber count, MnDOT part number, mode, and length in meters.

The RTMC had some issues with ice crush causing problems with fiber cables. Get input from them for the best installation method for fiber cable.

6.13.5 Wireless

With wireless communications you have to do a site survey to examine line of site. If the site survey is done in the winter, it may change in the spring when foliage returns to trees. Watch out for things that are likely to change in the future, like growth of trees or places where new buildings may be built in the line of site.

For power and communications, hardwired is best if it is feasible.

6.13.6 Leased Lines
(reserved)

6.14 New Technologies

Below are summaries of a number of new technologies. Further details can be found on the MnDOT ITS website, http://www.dot.state.mn.us/guidestar/projects.html.

6.14.1 Intersection Conflict Warning
(reserved)

6.14.2 Curve Warning System

The Minnesota Horizontal Curve Safety Improvement project evaluates the speed and/or crash impact of three permanently installed dynamic curve warning signs in three Minnesota counties.

6.14.3 Automated Vehicle Location (AVL)

Used for more than just vehicle location.

6.14.4 Tolling – MnPass

I-394, on the west side of the Twin Cities operates a High Occupancy Toll (HOT) lane. Carpooler's may use the lane for free and single occupant vehicles can opt to pay a toll to use the lane. The toll charged to single occupant vehicles varies according to conditions. The ongoing operations of I-394 allows for toll collection to be entirely automated (no manual fare collection).

6.14.5 Wildlife Crossing Warning System

The goal of this project is to reduce the number of large wildlife vehicle crashes on instrumented roadway sections by detecting large wildlife (deer, moose, etc.) and activating a flashing beacon on a standard deer sign, warning motorists of the presence of deer.

6.14.6 Bridge Warning Height System
(reserved)

6.14.7 Water on Road System
(reserved)

6.14.8 Fog Warning System
(reserved)
6.14.9 Warning of Stopped or Slow Traffic Ahead
Refer to the IWZ Handout (See Section 6.10 on page 6-23).

6.15 Experimental Technologies

6.15.1 Connected Vehicles
✓ National proof of concept.

6.15.2 Arterial Travel Times
Refer to the report:

6.15.3 Tolling
Based on amount of vehicle miles traveled.

6.15.4 5.9 GHZ radio
DSRC (dedicated short range communication). Might be under intelli-drive. Cross-cut across many technologies. High bandwidth wireless communication system.
7. SYSTEM DESIGN

7.1 Metro Design Checklist

Project Tracking/Handoff Sheet

RTMC Designer:

<table>
<thead>
<tr>
<th>N/A</th>
<th>Complete</th>
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</tr>
</tbody>
</table>

RTMC Maintenance and Operations contacted for issues within limits and scope Re:

| ☐   | ☐        | Loops |
| ☐   | ☐        | CCTV |
| ☐   | ☐        | RCS |
| ☐   | ☐        | DMS |
| ☐   | ☐        | Fiber/Vaults |
| ☐   | ☐        | Power/cables |
| ☐   | ☐        | Cabinets |
| ☐   | ☐        | Contact Metro Maintenance for vegetation removal |
| ☐   | ☐        | Metro Designer or Consultant |
| ☐   | ☐        | New services and addresses identified for John Kouth |
| ☐   | ☐        | Time and Traffic sent to Construction and Traffic (theoretically also the construction engineer) |
| ☐   | ☐        | Plan to Integrator for review |
| ☐   | ☐        | Specification to Integrator for review |
| ☐   | ☐        | State Furnished Materials list, verify draft with Integrator. (Note: This one is only costing info for engineers estimate) |
| ☐   | ☐        | Copy of plan sent to Locators – put memo in file |
| ☐   | ☐        | Plan and spec review hand off meeting prior to turn in. Date of this meeting? |

RTMC Integrator:

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<tr>
<th>N/A</th>
<th>Complete</th>
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</tr>
</tbody>
</table>
N/A Complete

- Material order sheet completed
- Purchase Orders completed
- Materials on hand
- Email Operation re: device baud rates and loop detector numbering
- Notified operation of impending outage or changes to system
- Verified adjoining systems for unintentional impacts
- Fiber designation labels for patch panels

**Inspections/meetings**

- Fiber cable testing/splicing
- Fiber cabinets
- Ramp Control Signals
- Camera poles
- CMS’s
- Outlet polarity checked at every cabinet

**Commissioning trip (if applicable)** – DMS, factor inspection trip, etc.

- Scheduled
- Completed

**Documentation** (who is going to receive the documentation)

- Testing and documentation issues: Positive feedback to Gary on anomalies and timeline expectations
- Fiber splicing updates passed to Scott H. (this should be incremental)
- MaintenanceP issues passed to Maintenance group and Design for documentation
- Labeling completed
- Red line Fiber diagrams to Design for CAD, (designer for R sheets, Scott H. for after project complete)

**Taking possession**

- John notifies Locators when it’s theirs to locate. Also send any red-line as-builts at this time.
- Integrators notify Operations of system up and running
- Hand off meeting with Maintenance to review project and any anomalies. Include for handoff 170 sheets, plan sheets and CMS warranty reminder. Dave of this meeting?

**RTMC Maintenance**

- Training on new devices??
- Maintenance Zone assigned (if applicable)
- List of project anomalies and new devices distributed to the group
7.2 Component Placement and Design

The purpose of this section is to present the fundamental procedures and standard practices related to the design of ITS components. This is presented in a series of design steps and the design considerations for each. First, the steps that are common to all components will be discussed. Then, the design steps that are applicable to individual components are addressed. These steps assume that the preliminary engineering, agreements and additional preparatory work has been performed.

7.2.1 General Step

<table>
<thead>
<tr>
<th>DESIGN STEP</th>
<th>DESIGN CONSIDERATION</th>
</tr>
</thead>
</table>
| Create or Get an Accurate Drawing of the Location | ✓ Review preliminary design checklist  
✓ Retain coordinates within CADD file – NAD83 coordinate system, county specific.  
✓ Review scope of project & project kick-off meeting info if appropriate  
✓ Request any additional survey or other information needed – obtain the field in place (FIP) files. FIP is a CADD file with physical installations and features  
✓ Check sight distances  
✓ Check cameras for blind spots. Normally 1 mile; may need to be denser.  
✓ Ramp control flasher considerations  
✓ DMS based on readability – longitudinal and horizontal concerns.  
✓ ITS designers should have an understanding of field cross-sections (ie, walls, ponds, etc.). This could greatly impact the placement of a device.  
✓ Check CADD file(s) for corrupt elements  
✓ Review field review notes  
✓ Obtain field measurements as appropriate to confirm CADD file  
✓ Show in-place elements in dashed (or gray scaled) and new construction solid.  
✓ The plans and/or specs should call for GPS locating of as-built installed equipment and underground cables to support future one-call locating requirements, as well as containing provisions for how the contractor should mark their dig locations and what level of locating they must agree to when digging.  
✓ Keep track of budgeting – preliminary budget estimate |

7.2.2 Detectors

<table>
<thead>
<tr>
<th>DESIGN STEP</th>
<th>DESIGN CONSIDERATION</th>
</tr>
</thead>
</table>
| Locate Mainline Detectors Also Refer to Section 6.2 | ✓ Speed loops, distance between is very important if using 2 loops  
✓ For speed detection, can get speed off of single loops (consult with the ITS group) |
<table>
<thead>
<tr>
<th>DESIGN STEP</th>
<th>DESIGN CONSIDERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>✓ For mainline, every half-mile in every lane (metro), also push for loops in shoulders for bus lanes</td>
</tr>
<tr>
<td></td>
<td>✓ For mainline detector, avoid in weaving areas. Get erroneous counts.</td>
</tr>
<tr>
<td></td>
<td>✓ For mainline detector, also avoid in areas where vehicles are slowing for merging traffic.</td>
</tr>
<tr>
<td></td>
<td>✓ Including some double loops to help in calibration of single loops.</td>
</tr>
<tr>
<td></td>
<td>✓ Naming of loops is very important, consult with ITS group for loop naming.</td>
</tr>
<tr>
<td></td>
<td>✓ Labeling, see notes in graphic on the following page.</td>
</tr>
<tr>
<td></td>
<td>✓ Passage loop set beyond ramp meter (at least 25’)</td>
</tr>
<tr>
<td></td>
<td>✓ Information used to check how many pass meter and get to passage loop</td>
</tr>
<tr>
<td></td>
<td>✓ Loop is approximately 3’ from edge of road (vary size)</td>
</tr>
<tr>
<td></td>
<td>✓ Queue detector upstream of meter. Look at ADT of ramp. If backing up over this loop, then approaching the limit</td>
</tr>
<tr>
<td></td>
<td>✓ Consider location for future elements.</td>
</tr>
<tr>
<td></td>
<td>✓ Numbering system comes from a database, Jessie Larson from RTMC Operation group. Number from right to left. N1, N2, etc. is for direction.</td>
</tr>
<tr>
<td>Locate Ramp Detection</td>
<td>✓ One per ramp with no meter, two per ramp if a meter.</td>
</tr>
<tr>
<td></td>
<td>✓ Check pavement conditions for placement of loops</td>
</tr>
<tr>
<td></td>
<td>✓ Typical project is a saw cut into concrete or level course, then overlay.</td>
</tr>
<tr>
<td></td>
<td>✓ For new construction, use a Never Fail preformed loop (Stabilized loop that cannot get water in them - You can specify the size).</td>
</tr>
<tr>
<td></td>
<td>✓ Do not place under a concrete reinforcing basket</td>
</tr>
<tr>
<td></td>
<td>✓ Do not place above a culvert (near reinforcements).</td>
</tr>
<tr>
<td></td>
<td>✓ Consider conduit runs when placing (paths to cabinet, pull boxes)</td>
</tr>
<tr>
<td></td>
<td>✓ For passage loop on ramps, place detector beyond HOV merge back location.</td>
</tr>
<tr>
<td></td>
<td>✓ If one on ramp, maybe further upstream should be considered</td>
</tr>
<tr>
<td></td>
<td>✓ Check on distance of Home Runs</td>
</tr>
<tr>
<td></td>
<td>✓ Might need to consider location of Queue detector. If an upstream pork-chop island, may have two movements feeding this.</td>
</tr>
<tr>
<td>Radar Detection</td>
<td>✓ Used in places with high merge areas, where a need to count the cars</td>
</tr>
<tr>
<td></td>
<td>✓ Also consider where the roadway is temporary.</td>
</tr>
<tr>
<td></td>
<td>✓ Side of road mounted radar may be blocked by proposed signs</td>
</tr>
<tr>
<td>Other detection technologies</td>
<td>✓ Consider other detection technologies as needed (see Section 6.2)</td>
</tr>
</tbody>
</table>
7.2.3 CCTV

<table>
<thead>
<tr>
<th>DESIGN STEP</th>
<th>DESIGN CONSIDERATION</th>
</tr>
</thead>
</table>
| Place CCTV                   | ✓ Placed at every mile (Metro)  
| (notes in this section could apply to urban and rural projects) | ✓ If on a straight stretch of road, place on every other side of the road  
|                               | ✓ If curved, place on outside of curve  
|                               | ✓ Check for blind spots caused by bridges/tunnels  
|                               | ✓ Be careful where you locate field items like signs or cameras to ensure that there is a place for a service vehicle to park by the roadside and a way to use a ladder or bucket truck to get at the installed equipment.  
|                               | ✓ Make sure the ground has been prepared where vehicle will park. If there has been a lot of rain, then need to make sure vehicle can use the area.  
|                               | ✓ Consider safety of maintenance vehicle during placement  
|                               | ✓ If lane closure is required, may take much more time to get this done. Can become very costly to close a lane (time, delays, etc.)  
|                               | ✓ If on a hinged pole, ensure that camera will drop down to a workable area. Place parallel with the road – ensure in the right direction.  

(In Cable with the Station: Deviated function for index no. 1)

NOTE:
LOOP DETECTOR FUNCTION DESIGNATIONS

(Same method shall apply to eastbound & westbound roads)
### System Design

- Cameras are labeled in order, start at 1, label sequential, west to east and south to north
  - Get number from operations center.
  - For arterial projects, cameras are placed for adequate coverage. This may/may not be a camera at every intersection (depends on spacing)

Place CCTV (Rural)

- Place on a higher elevation location
- Consider location of power. Can be a bigger issue in rural areas where power isn’t as readily available.
- Placement of the cabinet has to be accessible.
- Consider tree location. Consider when designing the time of year.
- For cabinet on the signal pole – currently mounted 10’ high
- Where is the signal being brought back to? What equipment is needed on the other end.

### 7.2.4 DMS

<table>
<thead>
<tr>
<th>DESIGN STEP</th>
<th>DESIGN CONSIDERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place DMS</td>
<td>✓ Be careful where you locate field items like signs or cameras to ensure that there is a place for a service vehicle to park by the roadside and a way to use a ladder or bucket truck to get at the installed equipment.</td>
</tr>
<tr>
<td></td>
<td>✓ Location of DMS</td>
</tr>
<tr>
<td></td>
<td>✓ Overhead for Urban. However, some ground mounted signs are used</td>
</tr>
<tr>
<td></td>
<td>✓ For arterials, side of road</td>
</tr>
<tr>
<td></td>
<td>✓ For rural, outside of clear zone. If not outside of clear zone, guardrail is</td>
</tr>
<tr>
<td></td>
<td>required. Height should be 7’ off of roadway.</td>
</tr>
<tr>
<td></td>
<td>✓ Is placement on a curve a consideration? Where is the optimal location when on the outside of a curve? Maybe the sign can before the curve so they are not distracted? Consider this placement for safety.</td>
</tr>
<tr>
<td></td>
<td>✓ New signs – specs on size of text. New size are now full matrix (so text could be entire size)</td>
</tr>
<tr>
<td></td>
<td>✓ Consider ROW issues</td>
</tr>
<tr>
<td></td>
<td>✓ Overhead requires a platform for maintenance – consider where is the truck going to be parked?</td>
</tr>
<tr>
<td></td>
<td>✓ DMS is placed on their own structure</td>
</tr>
<tr>
<td></td>
<td>✓ DMS is state furnished material</td>
</tr>
<tr>
<td></td>
<td>✓ Some are starting to design a maintenance vehicle pull-off pad. Level, cleared of snow.</td>
</tr>
<tr>
<td></td>
<td>✓ Consider where the source of power will come from</td>
</tr>
<tr>
<td></td>
<td>✓ Communication issues too. Sometimes have to consider power and communications when in rural areas. Might be a good source of power, but this could impact the communications.</td>
</tr>
<tr>
<td></td>
<td>✓ Place cabinet next to every DMS on the side of the road.</td>
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</tbody>
</table>

Also See Section 6.4

3 categories:
- ✓ Rural
- ✓ urban freeway
- ✓ arterial
### 7.2.5 Control Cabinets

<table>
<thead>
<tr>
<th>DESIGN STEP</th>
<th>DESIGN CONSIDERATION</th>
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</thead>
<tbody>
<tr>
<td>Place Ramp Meter Cabinets</td>
<td>✓ One per side of road</td>
</tr>
<tr>
<td></td>
<td>✓ Have unique ID per system</td>
</tr>
<tr>
<td><img src="image" alt="Image of ramp meter cabinets" /></td>
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</tr>
</tbody>
</table>
### 7.2.6 Power

<table>
<thead>
<tr>
<th>DESIGN STEP</th>
<th>DESIGN CONSIDERATION</th>
</tr>
</thead>
</table>
| Place Electrical Service Cabinet | ✅ Label with address  
|                               | ✅ Determine where SOP is  
|                               | ✅ Perform a voltage drop calculation if needed  
|                               | ✅ It is a good idea to have the service cabinet on its own  
|                               | ✅ Consider if you should tie into the power grid, use solar/wind                      |

<table>
<thead>
<tr>
<th>DESIGN STEP</th>
<th>DESIGN CONSIDERATION</th>
</tr>
</thead>
</table>
| Power Cables                 | ✅ For power and communications, hardwired is best if it is feasible.  
|                               | ✅ Have been putting communications over the power cables (can do Ethernet – all has to be on the same side of the transformer. Similar to Ethernet over twisted pair. More electronic equipment. |

### 7.2.7 Communications

<table>
<thead>
<tr>
<th>DESIGN STEP</th>
<th>DESIGN CONSIDERATION</th>
</tr>
</thead>
</table>
| Place Communications Cabinet | ✅ Shelter is a large communication cabinet (rural doesn’t have a give need for a shelter)  
|                               | ✅ Sign cabinet is often called the communication cabinet                                |

### Communications Cables

<table>
<thead>
<tr>
<th>DESIGN STEP</th>
<th>DESIGN CONSIDERATION</th>
</tr>
</thead>
</table>
| Communication Cables         | ✅ Fiber Optic - Consider the trunk fiber and the pigtails.  
|                               | ✅ For power and communications, hardwired is best if it is feasible.  
|                               | ✅ The RTMC had some issues with ice crush causing problems with fiber cables. Get input from them for the best installation method for fiber cable.  
|                               | ✅ Do not use steel conduit  
|                               | ✅ Use double jacketed, armored cable (helps to locate)  
|                               | ✅ Don’t have dips so water doesn’t pond  
|                               | ✅ Metro tries to place own fiber  
|                               | ✅ Some may share with private shares  
|                               | ✅ Shares with other government agencies  
|                               | ✅  Maybe sharing with vaults  
|                               | ✅ Single mode is all that is used as of now.  
|                               | ✅ Need an individual fiber for each component. Need a single fiber all the way back to the shelter  
|                               | ✅ When running everything analog, need 1 fiber                                       |


<table>
<thead>
<tr>
<th>DESIGN STEP</th>
<th>DESIGN CONSIDERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Consider the tradeoff cost between end equipment vs. cost of fiber. Also tradeoff on quality.</td>
<td></td>
</tr>
<tr>
<td>✓ If running single fiber, could lose multiple cameras (components) if the line is broken.</td>
<td></td>
</tr>
<tr>
<td>✓ Patch into the trunk at a shelter or a vault</td>
<td></td>
</tr>
<tr>
<td>✓ Some cities and counties have access to cable TV fiber</td>
<td></td>
</tr>
<tr>
<td>✓ When determining the number, consider cost to resplice too (if you cut 100, then need to splice 100). This also includes the testing.</td>
<td></td>
</tr>
<tr>
<td>✓ Have to manage fiber (what goes on each)</td>
<td></td>
</tr>
<tr>
<td>✓ If you do have a problem, need individuals with specialized equipment to fix this.</td>
<td></td>
</tr>
<tr>
<td>✓ With the pigtails, bringing into the cabinet and terminating there (arterials)</td>
<td></td>
</tr>
<tr>
<td>✓ Fiber is in the approved products list</td>
<td></td>
</tr>
</tbody>
</table>

**Communications Vaults**

<table>
<thead>
<tr>
<th>DESIGN STEP</th>
<th>DESIGN CONSIDERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Splice Vaults and Pull Vaults</td>
<td>✓ All underground</td>
</tr>
<tr>
<td></td>
<td>✓ This is an approved product</td>
</tr>
</tbody>
</table>

**Separation from Power Cables**

<table>
<thead>
<tr>
<th>DESIGN STEP</th>
<th>DESIGN CONSIDERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other</td>
<td>✓</td>
</tr>
</tbody>
</table>

### 7.7 Metro TMC Lessons Learned

1. Design review package must include sound walls, walls, cross sections and other pertinent information.
2. No source of power information was made available to review.
3. Need immediate financial penalty for not meeting or maintaining temporary systems.
4. ITS contractor needs to be more in the loop with prime and their work.
5. No removals were shown and this left us with issues at the end of the job.
6. Did not address in-place components.
7. Many mistakes
8. When changes were made or proposed, they always said they will show it on the as-builts, and would never update the active plan. This is a bad process, and prohibits good inspection.

9. Poor quality initial plans force us to do large share of design through redlining of the plan.

10. ITS designer did not take into account the staging of the project and changes had to be made because of this.

11. Notes not being on the same pages created huge issues and confusion.

12. Designers did not understand the fiber schematics they had to create.

13. Fiber schematics contained errors due to lack of understanding.

14. Schematics and the plan indicated different F&I features.

15. Beginning and ends of job did not represent clear impacts and responsibilities.

16. CMS design on bridge was not done to any MnDOT standard, contractor needed to get approval from RTMC as well as bridge on design.

17. Repair and warranty process does not work well for ITS, most if not all should be repaired within a week or two of reporting, not the current 48 hour emergency repair, and not the current end of warranty repair.

18. Contractor needs to raise issues they see as conflicting early on, instead of at the end where it is used only in their favor.

19. ASBUILTS need to be complete, full GPS and include updated notes.

20. Contractor did not give us good information on when MnDOT provided materials were needed.

21. Survey staking of design off of plans there were created without considerations of cross section is a bad idea. And the process to change is too cumbersome.

22. Detection placement issues.

23. Pole cabinet fiber conduit was not done properly due to staging.

24. Depth of conduit, this needs a verify method.

25. The inspector provided on the job (Cory) had no knowledge of any ITS components; we should not have to train the personnel.

26. The electrical did not want two punch list, one from Cory and then one from us. This needs to be clarified in the specs on how this should work.

27. Contractor needs to label professionally without us having to call out a label make and labeler model.

28. Poor compaction is causing cabinets to tilt and sidewalks to not be level.

29. Conduits were not plugged right away which cased rodents to find routes and create nest in our equipment. Several fiber cables were damaged due to rodents that got in due to no conduit plugging.

30. Fiber repairs were made without our knowledge or approval.

31. Conduits for blowing fiber were very ovaled and we had no spec to hold them to. No more SDR conduit will be used, only Schedule 40 and 80 which does have a spec will be used in the future.
32. Review, inspection and approval was being performed the same time as everyone was pushing for acceptance of the job, early documentation turn in would have help out this process.

33. Contractor needs to use wire connectors per color coded designed use.

34. Voltages need to be shown on the plan to indicate conductor use.

35. Too many hand holes in some areas.

36. Not enough hand holes by CCTV and cabinets.

37. Conduit placement was shown in areas of conflict. . .ie guard rails, bridge abutments, walls.

38. DMS placement and structure size.

39. Overhead power lines need to be factored into design.

40. Our involvement, when, where and how much was not laid out well.

41. Fiber blowing has damaged cable, are installers knowledgeable on how to run machines.

42. Require warranties and operating manuals. As part of the project development include an operations and maintenance plan so everyone knows who is responsible for what if there is a problem.

43. Consider purchasing a long term warranty for ongoing maintenance work.

44. Design the system to support maintenance, such as including status logging and diagnostic capabilities in the system.

45. Consider the best procurement approach. Sometimes it is better for the agency to separately purchase the technology and provide it to the contractor to install. If the project is using federal funds, it may be necessary to do a public interest finding and get it approved by the feds if you are going to purchase items separately and provide them to the contractor.
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8. PLAN DEVELOPMENT

8.1 Required Sheets

Standard ITS design plans shall contain at least the following sheets:

- Title Sheet
- General Layout Sheets (showing location of plan sheets)
- Symbols and Standard Plate Sheet(s)
- Estimated Quantities
- Component Layout Sheet(s), Construction Plans
- Detail Sheet Tabulation
- Details Sheets (may include one or more of the following)
  - Handhole Detail
  - Fiber Optic Pulling Vault, Splice Vault and Splice Vault Installation
  - Typical Foundation Details
  - Install FO Patching Shelter
  - Cabinet Details
  - Signing Layout Details
  - Sign Structural Details
  - Loop Detector Details
  - DMS Grounding Typical
  - CCTV Pole Detail and Pole Installation Detail
  - Pole Mounted Fiber termination Cabinet
  - Buried Cable Sign Placement Detail
  - Guiderail Installations
  - End Treatment Details
  - Fiber Distribution Equipment Details and Cable Labeling Details
  - Other(s)
- Communications Schematics/Testing
- Signing Plans
- Other(s)

Final signal plans should be prepared on 11” x 17” plan sheets. The original title sheet shall be of mylar or vellum composition. The scale for the “Intersection Layout” should be 40 scale (1:500 metric), interconnect layouts can be 100 scale (1:1000 metric). Each sheet of the plan must be properly identified in the lower right corner (State Project or State Aid Project Number and Sheet XX of XX).

The licensed professional engineer responsible for or under whose supervision the work is performed shall sign the title sheet.

8.2 Title Sheet

The title sheet is required for all ITS plans. It includes information such as the title block, project location, governing specifications, etc. A sample title sheet is shown below.
8.2.1 Plan Description and Location

This defines the type of work being performed and the location of the work. The location identified should list intersections from west to east or south to north.

8.2.2 Governing Specifications and Index of Sheets

This defines the governing specifications for the project, the project funding and the index of the sheets contained within the plan set. Generally it is located in the upper right hand corner of the title sheet, under the Federal Project number or statement “STATE FUNDS”.

If designed in metric units, there must also be a statement to the left of this box: “Attention, this is a metric plan”.

[Diagram of Minnesota Department of Transportation Construction Plan for Traffic Management System located on various metro highways]
8.2.3 Plan Preparation Certification Note

This identifies:

✓ Who the plan set was developed by (or under the direct supervision of)
✓ That individual’s state registration information.

I HEREBY CERTIFY THAT THE FINAL FIELD REVISIONS, IF ANY, WERE PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

PRINT NAME: _______________________________ LICENSE #: ___________________________
DATE: ___________________ SIGNATURE: ___________________________________________
8.2.4 Project Numbers and Sheet Numbers

The project numbers and sheet numbers are shown in the lower right hand corner of the title sheet and on all other sheets. For revisions to the plan made after project advertisement, an “R” shall be used after the sheet number.

A SP in the project number stands for State Project. A SP is necessary for any project on a trunk highway signal. A SAP is a State Aid Project number indicating that the local agency is using State Aid funds to finance their share of the project. If the project has federal funding the SAP becomes a SP. All state aid numbers should be listed on all sheets to which they apply.

The general format for a SP is “CCNN-A”. CC is the county number in alphabetical order (i.e., Anoka County is 02). NN is the control section number within the county unique to the roadway in the County. A is the number of the project on that control section (i.e., -269 means that there have been 268 other projects on this section of roadway prior to this project).

The general format for an SAP is CCC-NNN-A. CCC is a 3-digit city number, a two digit number is a county number. NNN is a number related to the roadway and project type. A is the number of the project in that city or county of that type.

8.2.5 Signature Block

8.2.6 Index Map

The index map is used to identify the location of the project(s). Provide leader lines from the beginning and end of the project limits to the appropriate points on the map. This is generally located near the center of the title sheet.

If appropriate, identify all State Aid project numbers applicable to the project. Also, label all traffic signal systems.
8.2.7 Project Location

The information included in this block is the generalized location (county and city). This is generally located in the lower right part of the title sheet, left of the signature block and above the project number block.
8.2.8 Plan Revisions Block
The block is included so that future plan revisions can be documented. This is generally located in lower center portion of the title sheet. Pencil in the charge identifier number. MnDOT plan processing will edit this as necessary.

<table>
<thead>
<tr>
<th>PLAN REVISIONS</th>
<th>APPROVED BY</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATE</td>
<td>SHEET NO.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8.3 General Layout Sheets
The general layout sheets show the layout of the sheets within the project area.
8.4 TMS Components Sheet

8.4.1 Legend of Symbols

These are the standard symbols and abbreviations pertaining to the design.
8.4.2 Utility Notes

These are the general Utility Notes.

**NOTE:**

**NO UTILITIES WILL BE AFFECTED BY THIS PROJECT.**

THE CONTRACTOR SHALL CALL GOPHER STATE ONE CALL FOR UTILITY LOCATES PRIOR TO BEGINNING ANY CONSTRUCTION.

GOPHER ONE STATE CALL IS MINNESOTA UNDERGROUND FACILITY NOTIFICATION CENTER (1-800-252-1166 OR 651-454-0002), IT SHOULD BE NOTED THAT IN ACCORDANCE WITH MINNESOTA STATUTE 216D, IT IS REQUIRED THAT ALL CONSTRUCTION PROJECTS INVOLVING MAINTENANCE ACTIVITY REQUIRE THE PARTY DOING THE EXCAVATION TO CALL GOPHER STATE ONE CALL 48 HOURS PRIOR TO EXCAVATION.

THE SUBSURFACE UTILITY INFORMATION IN THIS PLAN IS UTILITY QUALITY LEVEL D. THIS UTILITY QUALITY LEVEL WAS DETERMINED ACCORDING TO THE GUIDELINES OF CI/ASCE 38-02, ENTITLED “STANDARD GUIDELINES FOR THE COLLECTION AND DEPICTION OF EXISTING SUB SURFACE UTILITY DATA”

Utility Quality Level is a professional opinion about the quality and reliability of utility information. There are four levels of utility quality information, ranging from the most precise and reliable, level A, to the least precise and reliable, level D. The utility quality level must be determined in accordance with guidelines established by the Construction Institute of the American Society of Civil Engineers in document CI/ASCE 38-02 entitled “Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data.”

According to Minnesota Statutes, section 216D.04, subdivision 1a, all plans for projects with excavation must depict the utility quality level of the utility information. Unless there is proof that the utility information in the plan is more accurate, MnDOT assumes that it is Utility Quality Level D. The project manager must use the following note, filling in the appropriate utility quality level, on the utility tabulation sheets for projects involving excavation:

The subsurface utility information in this plan is utility quality level ___. This utility quality level was determined according to the guidelines of CI/ASCE 38-02, entitled “Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data.”

The Minnesota statute on utilities can be found at the following web site:

http://www.revisor.leg.state.mn.us/stats/216D/04.html
The plans and/or specs should call for GPS locating of as-built installed equipment and underground cables to support future one-call locating requirements, as well as containing provisions for how the contractor should mark their dig locations and what level of locating they must agree to when digging.

**8.4.3 List of Utility Ownership**

This is list of the utility ownership in the project area. The table includes a note of how the utilities should be impacted (i.e., LEAVE AS IS).

<table>
<thead>
<tr>
<th>Utility Owner</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access Communications, Incorporated</td>
<td>LEAVE AS IS</td>
</tr>
<tr>
<td>Rochester Center Ltd. 216</td>
<td>LEAVE AS IS</td>
</tr>
<tr>
<td>City of Brookline</td>
<td>LEAVE AS IS</td>
</tr>
<tr>
<td>City of Minneapolis</td>
<td>LEAVE AS IS</td>
</tr>
<tr>
<td>Comcast Cable Communications, Incorporated</td>
<td>LEAVE AS IS</td>
</tr>
<tr>
<td>Minneapolis County Public Works</td>
<td>LEAVE AS IS</td>
</tr>
<tr>
<td>Xcel Energy, L.P.</td>
<td>LEAVE AS IS</td>
</tr>
<tr>
<td>CenterPoint Energy Resources Corp., dba CenterPoint Energy</td>
<td>LEAVE AS IS</td>
</tr>
<tr>
<td>Minnesota Department of Transportation</td>
<td>LEAVE AS IS</td>
</tr>
<tr>
<td>Saint Paul Corporation</td>
<td>LEAVE AS IS</td>
</tr>
<tr>
<td>Real Energy</td>
<td>LEAVE AS IS</td>
</tr>
<tr>
<td>NIPCO Council, Environmental Services</td>
<td>LEAVE AS IS</td>
</tr>
<tr>
<td>Metropolitan Council, Environmental Services</td>
<td>LEAVE AS IS</td>
</tr>
<tr>
<td>Dakota County</td>
<td>LEAVE AS IS</td>
</tr>
<tr>
<td>St. Paul Public Utilities</td>
<td>LEAVE AS IS</td>
</tr>
</tbody>
</table>

**8.4.4 Standard Plates Summary**

This identifies the list of Standard Plates that are applicable to this project.

<table>
<thead>
<tr>
<th>Plate No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3131C</td>
<td>Precast concrete headwall for subsurface drains</td>
</tr>
<tr>
<td>80000</td>
<td>Standard barricades</td>
</tr>
<tr>
<td>91100</td>
<td>Traffic signal bracketing (pole mounted)</td>
</tr>
<tr>
<td>91110</td>
<td>Traffic signal bracketing (pedestal mounted)</td>
</tr>
<tr>
<td>912E</td>
<td>Pedestal foundation</td>
</tr>
<tr>
<td>9115C</td>
<td>Ground mounted cabinet foundation</td>
</tr>
<tr>
<td>8120M</td>
<td>Pole Foundation (PA 85)</td>
</tr>
<tr>
<td>8150C</td>
<td>Installation of culvert markers</td>
</tr>
<tr>
<td>8332C</td>
<td>W-beam guardrail &amp; end anchorages</td>
</tr>
<tr>
<td>9322K</td>
<td>Chain link fence (gates)</td>
</tr>
</tbody>
</table>
8.5 Quantities Sheet

This sheet shows the estimated quantities for the project. The Total Quantity and the quantity by project number shall be shown.

The appropriate specification item numbers, item descriptions, and units using the state’s computerized pay item list shall be included.

Refer to the TRNS*PORT Web Site ([www.dot.state.mn.us/stateaid/res_trnsport_list.html](http://www.dot.state.mn.us/stateaid/res_trnsport_list.html)) for a listing of the following:

- Item Number & Extension,
- Short Description,
- Long Description,
- Four Character Computer Code for the Unit Name, and
- Desired Plan Sheet Unit Name

State Aid participation should be clearly identified for each item.

Don’t forget to include software maintenance fees in your cost estimates.

8.6 Construction Plans

The Construction Layout sheet(s) includes the following (at a minimum):

- Roadway geometrics (to scale)
- All graphics depicting signal system components
- Component Installation notes
- Equipment pad notes (when applicable)
- Source of power notes (when applicable)
- Plan sheet title and revision block (on all sheets)
- A bar scale
- A north arrow
- Highway and/or Street names
- Metric logo (as necessary)
- Show utilities on the layout sheet on a case by case basis.
8.7 Detail Tabulation

<table>
<thead>
<tr>
<th>SHEET NO.</th>
<th>DETAIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>HANVALE DETAIL</td>
</tr>
<tr>
<td>35</td>
<td>FIBER OPTIC PULLING VAULT</td>
</tr>
<tr>
<td>36</td>
<td>FIBER OPTIC SPlice VAULT</td>
</tr>
<tr>
<td>37</td>
<td>FIBER OPTIC SPlice VAULT INSTALLATION</td>
</tr>
<tr>
<td>38</td>
<td>TYPICAL FOUNDATION DETAILS</td>
</tr>
<tr>
<td>39</td>
<td>INSTALL E'X'B' FD PATCHING SHELTER</td>
</tr>
<tr>
<td>40</td>
<td>TYPICAL 334 CABINET INSTALLATION</td>
</tr>
<tr>
<td>41</td>
<td>TMS SERVICE CABINET</td>
</tr>
<tr>
<td>42</td>
<td>TYPICAL 334 CABINET INSTALLATION</td>
</tr>
<tr>
<td>43</td>
<td>ONE-WAY RAMP CONTROL SIGNAL DETAIL</td>
</tr>
<tr>
<td>44</td>
<td>RAMP CONTROL SIGNAL CONTROL CABLE TERMINATION GUIDE</td>
</tr>
<tr>
<td>45</td>
<td>SIGNING LAYOUT DETAIL WITHOUT H.O.G. LANE</td>
</tr>
<tr>
<td>46</td>
<td>TYPE C &amp; D SIGN STRUCTURAL DETAILS (SHEET 1 OF 2)</td>
</tr>
<tr>
<td>47</td>
<td>TYPE C &amp; D SIGN STRUCTURAL DETAILS (SHEET 2 OF 2)</td>
</tr>
<tr>
<td>48</td>
<td>TMS SAWCUT LOOP DETECTOR TYPICAL - PART ONE</td>
</tr>
<tr>
<td>49</td>
<td>TMS LOOP DETECTOR TYPICAL - PART TWO</td>
</tr>
<tr>
<td>50</td>
<td>OWS GROUNDING TYPICAL</td>
</tr>
<tr>
<td>51</td>
<td>CCTV POLE DETAIL</td>
</tr>
<tr>
<td>52</td>
<td>CCTV POLE INSTALLATION DETAIL</td>
</tr>
<tr>
<td>53</td>
<td>POLE MOUNTED FIBER TERMINATION CABINET</td>
</tr>
<tr>
<td>54</td>
<td>BURIED CABLE SIGN PLACEMENT DETAIL</td>
</tr>
<tr>
<td>55</td>
<td>GUARDRAIL INSTALLATIONS AT MEDIANS AND END TREATMENTS (1 OF 3)</td>
</tr>
<tr>
<td>56</td>
<td>GUARDRAIL INSTALLATIONS AT MEDIANS AND END TREATMENTS (2 OF 3)</td>
</tr>
<tr>
<td>57</td>
<td>GUARDRAIL INSTALLATIONS AT MEDIANS AND END TREATMENTS (3 OF 3)</td>
</tr>
<tr>
<td>58</td>
<td>ET-2000 END TREATMENT (STEEL POSTS)</td>
</tr>
<tr>
<td>59</td>
<td>SKE-350 END TREATMENT (STEEL BOLTED HINGED POSTS)</td>
</tr>
<tr>
<td>60</td>
<td>FIBER DISTRIBUTION EQUIPMENT</td>
</tr>
<tr>
<td>61</td>
<td>FIBER DISTRIBUTION EQUIPMENT</td>
</tr>
<tr>
<td>62</td>
<td>FIBER OPTIC CABLE LABELING</td>
</tr>
</tbody>
</table>

8.8 Detail Sheets

The detail sheets show the standard details that are applicable to the project. They may include the following details.

- Detail for signal with a davit pole mounted CCTV
- Dynamic warning flasher detail
- Details for roadside mounted VMS
- Screw on base detail
8.8.1 Handhole Detail

8.8.2 Fiber Optic Pulling Vault
8.8.3 Fiber Optic Splice Vault
8.8.4 Typical Foundation Details

8.8.5 Fiber Distribution Patching Shelter
8.8.6 Typical Cabinet Installation

8.8.7 TMS Service Cabinet
8.8.8 Typical DMS 334 Cabinet Installation

8.8.9 One-way Ramp Control Signal Detail
8.8.10 Ramp Control Signal Control Cable Termination Guide

8.8.11 Signing Layout Detail (Without HOV)
8.9 Wiring Diagrams

The field wiring diagram is used to describe how the actual field wiring shall be placed. Some of the issues associated with this sheet include:

✓ (LIST IN DEVELOPMENT)

8.10 Fiber Connection Charts
**Plan Development**

---

**TMS Shelter Cabinet**

- Label the fiber optic splice enclosure on the outer jacket of both the splice enclosure and inside the splice enclosure.
- Label the fiber optic splice enclosure with the fiber optic splice enclosure number.
- Label the fiber optic splice enclosure with the fiber optic splice enclosure number and the fiber count.
- Label the fiber optic splice enclosure with the fiber optic splice enclosure number, direction, and fiber count.

---

**Fiber Optic Cable Labeling Detail**

- Label the fiber optic splice enclosure with the fiber optic splice enclosure number.
- Label the fiber optic splice enclosure with the fiber optic splice enclosure number, direction, and fiber count.

---

**MnDOT ITS Project Management Design Manual**

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9. STANDARD AND SPECIAL PROVISIONS

9.1 MnDOT Standard Specifications for Construction

http://www.dot.state.mn.us/pre-letting/spec/index.html

The “Spec Book” contains standard specifications to be used and referred to in the design of traffic plans and in the preparing of signal Special Provisions. Plan designers need to be aware of the specifications contained in the Spec Book that may apply to their individual project.

The 2005 Spec Book includes both metric and non-metric units of measure conversions. The 2005 Spec book also includes numerous modifications to the 2000 Spec Book. MnDOT produces a new Spec Book on a 5 year cycle.

9.1.1 Format of the “Spec Book”

The Spec Book is made of three divisions:

- Division I - General Requirements and Covenants
- Division II - Construction Details
- Division III - Materials

A section of Division I that all designers need to be particularly aware of is as follows:

MnDOT 1504 - “Coordination of Plans and Specifications”

“These Standard Specifications, the Plans, Special Provisions, supplemental Specifications, and all supplementary documents are essential parts of the Contract, and a requirement occurring in one is as binding as though occurring in all. They are intended to be complementary and to describe and provide for a complete work.

In case of discrepancy, calculated dimensions will govern over scaled dimensions; Special Provisions will govern over Standard and supplemental Specifications and Plans; Plans will govern over Standard and supplemental Specifications; supplemental Specifications will govern over Standard Specifications.

The Engineer will decide all issues concerning errors and omissions that are not otherwise resolved by logical conclusion or Contract modification. Both parties to the Contract shall inform each other as to any discrepancies they uncover, and neither the Contractor nor the Engineer shall take advantage of any error or omission.

In the interest of avoiding repetitious wording in the Specifications, certain words and phrases have been omitted where reference is clearly related by expressions of authority or intention. Where certain words and terms appear, they are to be construed with reference to the definitions, abbreviations, heading, titles, item names, and other pertinent provisions of the Contract documents, as may be implied.”

9.1.2 Format of MnDOT 2550 (Traffic Management System)

Division II contains MnDOT 2550 (Traffic Management System).

The format of MnDOT 2550 is as follows:

Description:

- Has a General information section.
- Has a Definitions section.
Materials:

- Has a General information section.
- Specifies various materials, including references to Division III of the Spec Book.

Construction Requirements:

- Has a General information section.
- Specifies the requirements for actually constructing either a traffic management system.

Method of Measurement:

- Traffic management systems are measured as an integral unit complete in place and operating with the complete installation at one system being considered one unit.

Basis of Payment:

- There is a payment schedule listed in this section that shows the Item No., Item, and Unit.

Division III includes a section entitled “Electrical Materials” which contains various material specifications for traffic management systems. The format of these material specifications are divided into: Scope, Requirements, and Inspection and Testing.

Other National and Local Standards

There are other national and local standards which are applicable to signal plans and specifications. The following are some of the standards specified in the Spec Book:

- AASHTO American Association of State Highway and Transportation Officials
- ASTM American Society of Testing and Materials
- ITE Institute of Transportation Engineers
- ICEA Insulated Cable Engineers Association
- NEC National Electrical Code
- NEMA National Electrical Manufacturers Association
- RUS Rural Utilities Service
- UL Underwriter Laboratories, Inc.

9.1.3 Supplemental Specifications

Supplemental specifications are additions and revisions to the standard specifications that are approved after the standard specifications book has been printed and distributed. They are published separately (usually in paperback booklet form) until the next updated Spec Book is published and released. The Plan and Proposal for each specific project needs to state if there are supplemental specifications that apply.

9.2 Approved Products List

The MnDOT approved products list can be found by visiting:

http://www.dot.state.mn.us/products/
10. APPENDIX A - SAMPLE PLAN
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<thead>
<tr>
<th>SHEET NO.</th>
<th>DETAIL</th>
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<tr>
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<td>CCTV POLE DETAIL</td>
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<tr>
<td>254</td>
<td>J-BOX WIRING DIAGRAM</td>
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<td>255</td>
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<td>261</td>
<td>ELECTRICAL SERVICE TYPICALS</td>
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<td>262</td>
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</tr>
</tbody>
</table>
STAN D ALONE
SERVICE FOUNDATION
(SEE TMS SERVICE EQUIPMENT DETAIL)

1. AFTER FOUNDATION AND
   CONDUITS ARE SET, FILL
   OPENING WITH SAND AND
   PLACE 1 INCH OF GROUT
   FLUSH WITH SURFACE OF
   FOUNDATION. GROUT
   SERVICE OPENING SHUT
   IF NOT USED.

3"x3"x4" SIDE WALK
(TYP.)

3"x5"x1'
EQUIPMENT PAD
(TYP.)

SEE STD. PLATE 8120 FOR
ANCHOR BOLT REQUIREMENTS

CENTER CONDUITS WITHIN BOLT PATTERN
MAX HEIGHT ABOVE FOUNDATION
INCLUDING BUSHING.

SEE STD. PLATE 8120

CONCRETE RAMP
CONTROL SIGNAL FOUNDATION
(SEE RAMP CONTROL SIGNAL DETAIL)

4" SPACER
(TYP.)

TYPICAL FOUNDATION DETAILS

NOT FOR CONSTRUCTION

(CCTV POLE FOUNDATION
SEE CCTV INSTALLATION DETAIL)

TYPICAL 334 SERIES
&W FOUNDATION
WITH SERVICE CABINET

TMS 334 CABINET
(TYP.)

FRONT VIEW
1/8 SCALE

SIDEWALK

CERTIFIED BY

LICENSED PROFESSIONAL ENGINEER
STAND ALONE
SERVICE FOUNDATION
(SEE TMS SERVICE EQUIPMENT DETAIL)

NOTE: INSTALL SCREW-IN RCS FOUNDATION WITHIN CONCRETE AREAS AS DIRECTED IN PLANS.

CENTER CONDUITS WITHIN BOLT PATTERN 2" MAX HEIGHT ABOVE FOUNDATION INCLUDING BUSSING.

SEE STD. PLATE B1120 FOR ANCHOR BOLT REQUIREMENTS

SEE STD. PLATE B1120

CENTER CONDUITS WITHIN BOLT PATTERN MAX HEIGHT ABOVE FOUNDATION INCLUDING BUSSING.

SEE STD. PLATE B1120

2" NMC (IF RSC IS USED WILL GROUND BUSCHING AND CONNECT TO BASE GROUNDING LUG WITH SOLID BARE NO. 6 WIRE)

TYPICAL 334 SERIES & DMS FOUNDATION WITH SERVICE CABINET

CONCRETE RAMP CONTROL SIGNAL FOUNDATION
(SEE RAMP CONTROL SIGNAL DETAIL)

SEE STD. PLATE B1120

TYPICAL FOUNDATION DETAILS

CERTIFIED BY

SHEET NO. OF SHEETS
1. Sawcut detectors in ramps & loops are variable sized, and installed in the center of the lane.

2. The loop detector conductors are 1/8" and 1/16" copper wires or copper clad tin. The wire is contained in a flexible polyethylene tubing.

3. Use a sealant made specifically to seal loop detector sawcuts in concrete roadways. Use an approved sealant in bituminous roadways and concrete roadways that are to be overlaid with bituminous.

4. Clean all debris from the entire loop detector area.

5. Mark the loop sawcuts on the roadway.

6. Saw the cut to 2 1/2" +/- 1/4" deep by 1/8" wider than the "go" of the conductor. Smooth the bottom and angles to prevent damage to insulation.

7. Clean the conduit ends, plug the conduit in the roadway to prevent the loop sealant from entering the conduit.

8. Drill the corners 1/4" deeper than the saw slot and smooth the hole corners.

9. Clean and dry the entire loop detector area.

10. Fix a bead of loop detector sealant to within 6" of loop conductors conduit. Install, clean, dry loop conductor running to the outside of the corners, do not install the connector tight. Push the conductors to the bottom of the saw slot with a blunt tool.

11. Place 3/4" diameter by 2" foam backer rod at 20" intervals to hold the conductor at the bottom of the saw cut, place loop sealant.

12. Fix a conductor per joint/crack detail each time a joint or pavement crack is crossed.

13. Twist the conductors 9 turns per meter in the conduit from the roadway to the splice within the saw cut.

14. Solder the loop conductor to lead-in leaving the joint staggered. Redecorate cable jacket with sandpaper, place into splice encapsulator with a plastic tube and end caps that function as spouts. Use a 3/8" port encapsulating resin, and cap it in a urethane. Stir to blend and use within the encapsulator. After the saw cut is cured, fill both loop conductors and lead-in wire into the saw cut and encapsulate the splice.

15. Sawcuts shall remain 2.0" from other sawcuts.

16. Fill saw cut uniformly according to the loop sealant manufacturer's recommended depth. Wipe all excess sealant material from the roadway surface.

---

**SAW CUT LOOP DETECTOR TYPICAL-PART ONE**

**JOINT/Crack INSTALLATION**

**DRILL SAWCUT CORNERS**

---

**MAINLINE DETECTORS**

**QUEUE LOOPS**

---

**RAMP LOOP**
GENERAL NOTES:

1. SEE SPECIAL PROVISIONS FOR REQUIRED LOOP DETECTOR CONDUCTOR SPICE KIT.

2. THE LOOP DETECTOR HEAD SHALL BE 5/8" C.D. POLYPROPYLENE CONDUIT AND SHALL BE ENCRUSTED WITH PVC PRERUGGEDIZED ASPHALT AFTER CONDUCTOR PLACEMENT TO ENCOURAGE THE WIRE AND PROVIDE A MOISTURE BARRIER

3. PREPERFORATED LOOP DETECTORS ARE VARIABLE SIZED DEPENDING ON ROADWAY LOCATION AND SHALL BE INSTALLED IN THE CENTER OF THE LOOP. PAVEMENT JOINTS FOR CONCRETE PAVING SHALL BE ERECTED BEFORE LOOP PLACEMENT TO MAINTAIN A MIN. OF 30" FROM DOWEL BASKET PLACEMENT

4. THE LOOP DETECTOR CONDUCTOR IS 1/2" NO. 16 STRANDED COPPER WITH DWR INSULATION

5. THE PROTECTED LEAD PORTION OF LOOP SHALL EXTEND FROM THE CONDUCTOR, ENDING A MIN. OF 1" INSIDE THE PVC CONDUIT

6. THE LOOP DETECTOR CONDUCTORS SHALL BE WIRE THREE TIMES PER FOOT FROM THE PVC TEE CONNECTOR TO THE HANDHOLE

7. EACH LOOP DETECTOR CONDUIT TO THE HANDHOLE SHALL BE SLOPED TOWARDS THE HANDHOLE

8. THE LOOP DETECTOR CONDUCTORS SHALL END IN THE HANDHOLE

9. NO SPLICES ALLOWED IN LOOP CONDUCTOR EXCEPT AT HANDHOLE

10. SEE SPECIAL PROVISIONS FOR TESTING REQUIREMENTS OF LOOP DETECTORS

11. THE LOOP DETECTOR CONDUCTORS AND THE LOOP DETECTOR LEAD-IN CABLE CONDUCTORS SHALL BE PROPERLY PREPARED AND CLEANED BEFORE SPLICING. SOLDER THE LOOP CONDUCTOR TO LEAD-IN CONDUCTORS, THEN PLACE IT INTO THE SLEEVE ENCAPSULATION

12. INSTALL THE SLEEVE IN A PLASTIC TUBE WITH END CAPS THAT FUNCTION AS NUTS. USE A TWO PART INSULATING RESIN, COMBINED IN A FRIGAR, THAT TURNS BLACK WHEN MIXED AND BECOMES HARD WHEN CURED. FLEX BOTH LOOP CONDUCTORS AND LEAD-IN INTO THE SAME END OF THE TUBE AND ENCRUST THE SLEEVE

13. THE LOOP INSULATION RESISTANCE READINGS MUST BE GREATER THAN 1000 MW OHM

14. "NEVER FAIL LOOP SYSTEMS" DETECTOR WOOL A WITH THE WOOL PART NUMBER NOTED BELOW HAS MET THESE REQUIREMENTS

MODEL A

- LENGTH
- 84-REARRED WIDTH
- 4 TURNS
- 5" PROTECTED LEAD

A6XX4590-XTH-W-MN

- WIRE TYPE
- 80' UNPROTECTED LEAD

PART NUMBER INFORMATION

REV. NO.  DATE / /
REV. NO.  DATE / /

CERTIFIED BY  LICENSED PROFESSIONAL ENGINEER

TMS "PREFORMED" LOOP DETECTOR-PART ONE

TYPICAL PREFORMED LOOP DETECTOR DETAIL
<table>
<thead>
<tr>
<th>SIGN</th>
<th>POSTS (3)</th>
<th>MOUNT HT. (FT)</th>
<th>PANEL LEGEND</th>
</tr>
</thead>
<tbody>
<tr>
<td>R3-X3</td>
<td>2U</td>
<td>15.5</td>
<td>HOV RAMP</td>
</tr>
<tr>
<td>R10-X6</td>
<td>(1)</td>
<td>24 x 18</td>
<td>1 CAR ON GREEN</td>
</tr>
<tr>
<td>R10-X7</td>
<td>(1)</td>
<td>24 x 30</td>
<td>FORM 2 LANES WHEN METERED</td>
</tr>
<tr>
<td>R3-X3</td>
<td>(1)</td>
<td>24 x 30</td>
<td>SIGNAL AHEAD R-Y-G</td>
</tr>
<tr>
<td>X4-2</td>
<td>(2)</td>
<td>12 x 18</td>
<td>HAZARD WARNING (4)</td>
</tr>
</tbody>
</table>

**NOTE:**
1. PLACED ON RAMP CONTROL SIGNAL POLE
2. PLACED ON R3-X3 HOV MOUNTING POSTS
3. POST LENGTHS ARE APPROXIMATE AND INCLUDE ENSEMBLY, BUT DOES NOT INCLUDE ADDITIONAL LENGTH REQUIRED FOR SPlicing.
4. BLACK BACKGROUND, FLUORESCENT YELLOW SHEETING
VAULT INSTALLATION & DRAINAGE SYSTEM (SLOPED AREAS)

- Install vault protector (ADAPTED BY WDNDT)
- 4" x 1/2" GRND RED INSTALLED IN ACCORDANCE WITH MNDOT 2555.3
- 4" PVC CHAS 35 AT 1.0 X MIN. GRAD TO DAYLIGHT
- 4" RIGID PVC CHAS 35 AT 1.0 X MIN. GRAD TO DAYLIGHT
- INSTALL MORTAR POST PER STL PLATE 8950
- 2-1/2" X 4" PULL SLOTS FOR COVER LIFTING UNITS
- MOUNT LOCATOR BALL WITH TIE WRAP TO LEDGE

VAULT INSTALLATION & DRAINAGE SYSTEM (LEVEL GROUND & ACHIEVABLE DRAINAGE AREAS)

- Install vault protector (ADAPTED BY WDNDT)
- 4\" PVC CHAS 35 AT 1.0 X MIN. GRAD TO DAYLIGHT
- INSTALL MORTAR POST PER STL PLATE 8950

SPECIFIC NOTES:
1. OPENINGS FOR CONDUIT SHALL BE SEALED WITH MATERIAL COMPATIBLE SEALANT (INCIDENTAL)
2. PLUG CONDUIT OPENING WITH A DRAINABLE COMPOUND (INCIDENTAL)
3. 1.0" COARSE FILTER AGGREGATE UNDER BASE, COMPLIANCE WITH MNDOT 3341.24.1L
4. 4" PERFORATED PVC PIPE WITH FILTER SOCK TO PROVIDE DRAINAGE (INCIDENTAL)
5. RESTORE DISTURBED AREAS FOR PVC INSTALLATION WITH SEED AND TYPE 1 NELCH PER MNDOT 2575.3 (INCIDENTAL)
6. STRIP TOPSOIL FROM VAULT AND SLOPE AREAS PRIOR TO VAULT INSTALLATION (INCIDENTAL)
7. MOUNT LOCATOR BALL WITH TIE WRAP TO COVER LEDGE
8. SHEATH GROUNDING DEVICE AND GROUND ROG ARE NOT INSTALLED IN VAULTS WHERE SPACING DOES NOT TAKE PLACE.
9. DRAIN PIPE MAY BE INSTALLED IN SIDEWALL OF PULL VIAL TO ACHIEVE DRAINAGE IN AREAS WHERE MINIMUM PIPE OUTFALL IS AVAILABLE.

FIBER OPTIC PULL VAULT AT SPlicing LOCATIONS INSTALLATION DETAIL

GENERAL NOTES:
1. GROUND CONNECTIONS SHALL BE SEALED WITH OXIDATION PROHIBITING COMPOUND.
2. CABLE SHALL ENTER BELOW THE SUPPORT BRACKETS WITH MIN. 1/4" OF SLACK FOR EACH CABLE EXPOSED INSIDE OF THE ENCLOSURE. CABLES SHALL BE COILED AROUND INSIDE OF SUPPORT BRACKETS. CABLES SHALL BE CUT TO THE SAME LENGTH AT THE ENCLOSURE.
3. DO NOT LIFT ENTIRE PULL VIAL WITH COVER ATTACHED BY COVER LIFTING SLOTS.
VAULT INSTALLATION (SLOPED AREAS)

VAULT INSTALLATION (LEVEL GROUND)

SPECIFIC NOTES
1. Openings for conduit shall be sealed with material compatible sealant, (incidental).
2. Plug conduit opening with a drainable compound, (incidental).
3. Mount locator ball with tie-wrap to cover ledge.
4. Restore disturbed areas for TMS installation with seed and type I mulch per MDOT 2375.3 (incidental).
5. Strip topsoil from vault and slope areas prior to vault installation, (incidental).

GENERAL NOTES
1. Ground connections shall be coated with oxidation prohibiting compound.
2. Do not lift entire pull vault with cover attached by cover lifting slots.

FIBER OPTIC PULL VAULT INSTALLATION DETAIL

CERTIFIED BY:

LICENSED PROFESSIONAL ENGINEER

STATE PROJECT NO. 0207-94

SHEET NO. 75 OF 99 SHEETS
CIRCUIT PANEL DETAIL

ELECTRICAL NOTES:
1. All wiring shall be in accordance with the National Electrical Code.
2. All electrical materials shall be UL listed and classified as suitable for the purpose specified.
3. All wiring shall be subject mounted in a raceway or low voltage conduit using nonmetallic connectors. Cords, cable, and clamps. All conduit shall be armored in place at approximately every 4 ft.
4. All wiring shall be a twisted conductor. Then, either, no smaller than a N.M.
5. All wiring must be insulated.
6. Low voltage wires must be in raceway. They shall be protected by a qualified inspector prior to shipments.
7. Ground conductors shall be run to all of the building's low voltage devices. Ground conductors shall not be used as the sole source of ground.
8. All alarm devices shall be run in its own conduit to the alarm cabinet.

CONSTRUCTION NOTES:
1. SKID ASSEMBLY: The skid assembly shall consist of 6" x 8" beam welded to 1/2" x 2" x 14' schedule 40 pipe running through the beams. The beams and a 3" x 3" x 14' angle plate is between the beams. The assembly is designed to hold the skid at 4'-8" to the ground. The skid assembly shall be painted with rust protective paint and sealed to the floor with 3/8" x 3/8" lag bolts every 14".

NOTE: All dimensions shown are inside dimensions.

INTERIOR LAYOUT FOR
10' W. OD X 12' L. OD X 9'H. ID BLDG.

SAMPLE PLAN

SEE NEXT SHEET FOR FLOOR LAYOUT DETAILS

<table>
<thead>
<tr>
<th>NO.</th>
<th>QTY.</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>3&quot; X 3&quot; STEEL INSULATED DOOR AND FRAME W/BRAZED ON ENAMEL PAINT W.S.S. BALL BEARING HINGES W/NON REMOVEABLE PINS, SCHLAGE PASSAGE AND DEADBOLT.</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>LIGHT SWITCH, SPEC GRADE</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>A/R 4&quot; SQ. WIRE RACEWAY WITH HINGED COVER</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>120/240V, SINGLE PHASE, 20 POSITION DISTRIBUTION PANEL W/100A. MAIN BREAKER</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>AIR CONDITIONER/HEATER THERMOSTAT</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>DUPLEX RECEPTACLES, 110V. 20A. NOT FOR OVERHEAD RECEPTACLES IN A VERTICAL POSITION</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>WALL MOUNT.AIR COND. 3 TON W/230V</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>4&quot; 2 BULB FLUORESCENT LIGHT FIXTURE</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>200 AMP TRANSFER SWITCH</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>100 AMP MAIN DISCONNECT, 500 120/240V</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>200 A. GENERATOR RECIPI</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>JUNCTION BOX (FOR SECURITY ACCESS)</td>
</tr>
</tbody>
</table>

PROPOSED BMS SHELTER DETAIL SHEET 1

CERTIFIED BY L.C. NO. DATE STATE PROJ. NO. SHEET NO. OF SHEE
NOTE:
EACH INSTALL DMS ITEM SHALL INCLUDE THE INSTALLATION OF A 1½" ONE PIECE GROUND ROD AND THE INSTALLATION OF THE ¼" GROUNDING BRAID STRAPPED TO THE POWER CONDUIT OR SIGN POST AS INDICATED.

THE DMS GROUNDING BRAID WILL BE CONTINUOUS FROM THE DMS GROUND LUG THROUGH THE GROUND ROD EXOTHERMICAL WELD TO THE INTERNAL SIGN POST GROUND LUG WHEN APPPLICABLE.

STRAP GROUNDING BRAID TO POST OR CONDUIT AWAY FROM VIEW OF TRAFFIC.

DMS GROUNDING BRAID IS CONSTRUCTED OF 32 STRANDS OF 17 GAUGE COPPER WIRE, ¼" DIAMETER, BRAIDED SMOOTH TWIST, 65,500 CIRCULAR MILS, NET WEIGHT 215 LBS. PER 1000 FT.

F&A GROUND ROD AND EXOTHERMICALLY WELD OR MECHANICALLY CLAMP TO THE DMS GROUNDING BRAID.

DMS GROUNDING TYPICAL

(Not For Construction)
GENERAL NOTES

- Add cable identifiers to color coded electrical tape with a permanent marker as shown on this detail.
  - e.g.: 94.41 East 24SM 01467M.
  - 94.41 = Cable ID
  - East = Direction
  - 24SM = Cable fiber count
  - 01467 = Nearest cable length marking to where the tape is applied.

- Electrical tape colors:
  - NO (Blue)
  - S1 (Green)
  - E1 (Yellow)
  - FY (Orange)
  - Pigtail (White)
  - The electrical tape with the identifiers is added to:
    - 3247-Type Cabinets to within 18" of the entrance conduit on the outer jacket of the fiber optic cable.
    - Pole Mounted CCTV Cabinet between the entrance point and the fiber termination panel.
  - FO Splice Vault to within 18" of the splice enclosure and the entrance conduit.
  - TMS Shelter Cabinets to within 18" of the entrance conduit on the outer jacket of the fiber optic cable and again to within 18" of the splice panel on the inner jacket of the fiber optic cable.

- Neatly tape the fiber optic cables together as needed near the fiber enclosure then throughout the length of slack.

- Neatly coil the fiber optic cables into the fiber optic hanger brackets inside the vault.

- This drawing is not intended to show the fiber optic cables in their final position.

TMS SHELTER CABINET

- Label the indoor pigtail six-packs on the outer jacket at both the splice tray/wheel and inside the patch panel to indicate the fiber cable ID and which six fibers the six-packs are spliced to: (e.g. 94-12 SM7-12)
  - Label the front of the splice panels with the fiber cable ID, direction, and fiber count.
  - Label the front of patch panels with the fiber cable ID, direction and fiber count.
  - Label the sheath grounding unit with the fiber cable ID, direction and fiber count.

FIBER OPTIC CABLE LABELING DETAIL

PLEASE NOTE: OUTDOOR FIBER SPlice ENCLOSURE IS SHOWN OUTSIDE OF THE SPICE VAULT. THE ACTUAL PLACEMENT IS WITHIN THE VAULT HANGING ON BRACKETS (NOT SHOWN)
11. **APPENDIX B - 23 CFR SECTION 940**
Monday,
January 8, 2001

Part IV

Department of Transportation

Federal Highway Administration

23 CFR Parts 655 and 940
Intelligent Transportation System
Architecture and Standards; Final Rule

Federal Transit Administration

Federal Transit Administration National
ITS Architecture Policy on Transit
Projects; Notice
DEPARTMENT OF TRANSPORTATION

Federal Highway Administration

23 CFR Parts 655 and 940
[FHWA Docket No. FHWA–99–5899]

RIN 2125–AE65

Intelligent Transportation System Architecture and Standards

AGENCY: Federal Highway Administration (FHWA), DOT.

ACTION: Final rule.

SUMMARY: The purpose of this document is to issue a final rule to implement section 5206(e) of the Transportation Equity Act for the 21st Century (TEA–21), enacted on June 9, 1998, which required Intelligent Transportation System (ITS) projects funded through the highway trust fund to conform to the National ITS Architecture and applicable standards. Because it is highly unlikely that the entire National ITS Architecture would be fully implemented by any single metropolitan area or State, this rule requires that the National ITS Architecture be used to develop a local implementation of the National ITS Architecture, which is referred to as a “regional ITS architecture.” Therefore, conformance with the National ITS Architecture is defined under this rule as development of a regional ITS architecture within four years after the first ITS project advancing to final design, and the subsequent adherence of ITS projects to the regional ITS architecture. The regional ITS architecture is based on the National ITS Architecture and consist of several parts including the system functional requirements and information exchanges with planned and existing systems and subsystems and identification of applicable standards, and would be tailored to address the local situation and ITS investment needs.


FOR FURTHER INFORMATION CONTACT: For technical information: Mr. Bob Rupert, (202) 366–2194, Office of Travel Management (HOTM–1) and Mr. Michael Freitas, (202) 366–9292, ITS Joint Program Office (HOIT–1). For legal information: Mr. Wilbert Baccus, Office of the Chief Counsel (HCC–32), (202) 366–1346, Federal Highway Administration, 400 Seventh Street, SW., Washington, DC 20590. Office hours are from 8 a.m. to 4:30 p.m., e.t., Monday through Friday, except Federal holidays.

SUPPLEMENTARY INFORMATION:

Electronic Access and Filing

You may submit or retrieve comments online through the Docket Management System (DMS) at: http://disodes.dot.gov/submit. Acceptable formats include: MS Word (versions 95 to 97), MS Word for Mac (versions 6 to 8), Rich Text Format (RTF), American Standard Code Information Interchange (ASCII) (TTX), Portable Document Format (PDF), and WordPerfect (version 7 to 8). The DMS is available 24 hours each day, 365 days each year. Electronic submission and retrieval help and guidelines are available under the help section of the web site.


Background

A notice of proposed rulemaking (NPRM) concerning this rule was published at 65 FR 33994 on May 25, 2000, and an extension of the comment period to September 23, 2000, was published at 65 FR 45942 on July 26, 2000.

In the NPRM on this rule, the FHWA had proposed that the regional ITS architecture follow from the ITS integration strategy proposed in another NPRM entitled “Statewide Transportation Planning: Metropolitan Transportation Planning” published at 65 FR 33922 on May 25, 2000. That rule is being developed according to a different schedule and will be issued separately. For this reason, all references to the proposed integration strategy have been removed from this rule. However, it is still the intent of this rule that regional ITS architectures be based on established, collaborative transportation planning processes. The other major changes to the final rule relate to options for developing a regional ITS architecture and the time allowed to develop such an architecture. Additional changes to the final rule largely deal with clarification of terms, improved language dealing with staging and grandfathering issues, and clarification of the use of ITS standards. Intelligent Transportation Systems represent the application of information processing, communications technologies, advanced control strategies, and electronics to the field of transportation. Information technology in general is most effective and cost beneficial when systems are integrated and interoperable. The greatest benefits in terms of safety, efficiency, and costs are realized when electronic systems are systematically integrated to form a whole in which information is shared with all and systems are interoperable.

In the transportation sector, successful ITS integration and interoperability require addressing two different and yet fundamental issues; that of technical and institutional integration. Technical integration of electronic systems is a complex issue that requires considerable up-front planning and meticulous execution for electronic information to be stored and accessed by various parts of a system. Institutional integration involves coordination between various agencies and jurisdictions to achieve seamless operations and/or interoperability. In order to achieve effective institutional integration of systems, agencies and jurisdictions must agree on the benefits of ITS and the value of being part of an integrated system. They must agree on roles, responsibilities, and shared operational strategies. Finally, they must agree on standards and, in some cases, technologies and operating procedures to ensure interoperability. In some instances, there may be multiple standards that could be implemented for a single interface. In this case, agencies will need to agree on a common standard or agree to implement a technical translator that will allow dissimilar standards to interoperate. This coordination effort is a considerable task that will happen over time, not all at once. Transportation organizations, such as, transit properties, State and local transportation agencies, and metropolitan planning organizations must be fully committed to achieving institutional integration in order for integration to be successful. The transportation agencies must also coordinate with agencies for which transportation is a key, but not a primary part of their business, such as, emergency management and law enforcement agencies.

Successfully dealing with both the technical and institutional issues requires a high-level conceptual view of the future system and careful, comprehensive planning. The framework for the system is referred to as the architecture. The architecture defines the system components, key functions, the organizations involved, and the type of information shared.
between organizations and parts of the system. The architecture is, therefore, fundamental to successful system implementation, integration, and interoperability.

Additional background information may be found in docket number FHWA–99–5899.

The National ITS Architecture

The Intermodal Surface Transportation Efficiency Act of 1991, Public Law 102–240, 105 Stat. 1914, initiated Federal funding for the ITS program. The program at that time was largely focused on research and development and operational tests of technologies. A key part of the program was the development of the National ITS Architecture. The National ITS Architecture provides a common structure for the design of ITS systems. The architecture defines the functions that could be performed to satisfy user requirements and how the various elements of the system might connect to share information. It is not a system design, nor is it a design concept. However, it does define the framework around which multiple design approaches can be developed, each one specifically tailored to meet the needs of the user, while maintaining the benefits of a common approach.

The National ITS Architecture, Version 3.0 can be obtained from the ITS Joint Program Office of the DOT in CD–ROM format and on the ITS web site http://www.its.dot.gov. The effort to develop a common national system architecture to guide the evolution of ITS in the United States over the next 20 years and beyond has been managed since September 1993 by the DOT. The National ITS Architecture describes in detail what types of interfaces should exist between ITS components and how they will exchange information and work together to deliver the given ITS user service requirements.

The National ITS Architecture and standards can be used to guide multi-level government and private-sector business planners in developing and deploying nationally compatible systems. By ensuring system compatibility, the DOT hopes to accelerate ITS integration nationwide and develop a strong, diverse marketplace for related products and services.

It is highly unlikely that the entire National ITS Architecture will be fully implemented by any single metropolitan area or State. For example, the National ITS Architecture contains information flows for a Automated Highway System that is unlikely to be part of most regional implementations.

However, the National ITS Architecture has considerable value as a framework for local governments in the development of regional ITS architectures by identifying the many functions and information sharing opportunities that may be desired. It can assist local governments with both of the key elements: technical interoperability and institutional coordination.

The National ITS Architecture, because it aids in the development of a high-level conceptual view of a future system, can assist local governments in identifying applications that will support their future transportation needs. From an institutional coordination perspective, the National ITS Architecture helps local transportation planners to identify other stakeholders who may need to be involved and to identify potential integration opportunities. From a technical interoperability perspective, the National ITS Architecture provides a logical and physical architecture and process specifications to guide the design of a system. The National ITS Architecture also identifies interfaces where standards may apply, further supporting interoperability.

Transportation Equity Act for the 21st Century

As noted above, section 5206(e) of the TEA–21, Public Law 105–178, 112 Stat. 457, requires ITS projects funded from the highway trust fund to conform to the National ITS Architecture, applicable or provisional standards, and protocols. One of the findings of Congress in section 5202 of the TEA–21, is that continued investment in systems integration is needed to accelerate the rate at which ITS is incorporated into the national surface transportation network. Two of the purposes of the ITS program, noted in section 5203(b) of the TEA–21, are to expedite the deployment and integration of ITS, and to improve regional cooperation and operations planning for effective ITS deployment. Use of the National ITS Architecture provides significant benefits to local transportation planners and deployers as follows:

1. The National ITS Architecture provides assistance with technical design. It saves considerable design time because physical and logical architectures are already defined.
2. Information flows and process specifications are defined in the National ITS Architecture, allowing local governments to accelerate the process of defining system functionality.
3. The architecture identifies standards that will support interoperability now and into the future, but it leaves selection of technologies to local decisionmakers.

4. The architecture provides a sound engineering framework for integrating multiple applications and services in a region.

ITS Architecture and Standards NPRM Discussion of Comments

The FHWA received 105 comments on this docket from a wide range of stakeholders, including major industry associations, State departments of transportation, Metropolitan Planning Organizations (MPOs), and local agencies. The comments were generally favorable about the scope and content, but requested additional clarification and guidance on implementation of specific items. On many issues, some commenters wanted more specific requirements, while others wanted more flexibility. Most commenters, including major industry associations and public sector agencies, agreed with the overall scope, but some felt that the specifics might be difficult to implement and asked for clarification of key terms. A few commenters wanted the FHWA to reduce the number of requirements or convert the rulemaking into a guidance activity until more ITS deployment experience is gained.

In summary, the FHWA received a large number of generally favorable comments about the NPRM that suggested minor specific changes and expressed a need for further guidance on implementation. Since the general tenor of the comments was positive, the FHWA has kept the scope of the NPRM and made appropriate clarifications to the text of the final rule to address concerns raised in comments. In response to the many comments requesting it, starting in early 2001, the FHWA will also provide a program of guidance, training, and technical support to assist with the implementation of this rule. The following is a detailed discussion of the comments and their disposition, organized by subject matter.

Section 940.3 Definitions

ITS Project. There were 34 comments submitted to the docket concerning the definition of an ITS project. Many of the commenters felt the definition was not clear enough, was too broad, or was too subject to interpretation. Some comments questioned how much of a project’s budget would have to be spent on ITS before a project would be considered an ITS project. Some suggested specific language to more narrowly define an ITS project by
focusing on the portion of the overall project that is actually ITS or by suggesting language that would narrow the definition of an ITS project to only include projects which introduce new or changed integration opportunities.

Since the intent of this rule and the supporting legislation is to facilitate the deployment of integrated ITS systems, it is the position of the FHWA that the definition of an ITS project must be fairly broad to include any ITS system being funded with highway trust fund dollars. It is only by properly considering all planned ITS investments in the development of a regional ITS architecture that the integration opportunities and needs can even be identified. This consideration should be carried out in the development of an architecture prior to the specific project being advanced. If, in the development of a regional ITS architecture, it is determined that a specific planned project offers no real integration opportunities for the region, then the impact of this rule on that specific project is minimal.

As a response to the comments concerning the clarity of the definition, the definition of an ITS project has been slightly modified to remove the examples since they were considered misleading. The FHWA recognizes that any definition will be subject to interpretation by the stakeholders and acknowledges the need for guidance in this area to ensure clear and consistent interpretation of this rule. Guidance on what constitutes an ITS project (including examples) will be developed to assist the various stakeholders, including the FHWA Division Offices, to better understand what projects should be considered ITS projects.

Region. There were 26 comments submitted related to the definition of a region. Seven comments supported the open definition provided in the NPRM, arguing that the possible integration opportunities in an area should define the region and that there were too many possible variations to allow a restrictive definition. Six commenters who expressed concern over varying conditions interpreted the definition to mean Metropolitan Planning Area (MPA). Five comments suggested an MPA was too restrictive. Eight other comments indicated that the proposed definition of a region did not clearly identify what entity would have the lead in developing a regional ITS architecture or thought the definition implied the MPO should have the lead. Nine suggested various limits or boundaries to fit specific situations. Ten comments expressed a need for greater clarification of the definition for a region.

The intent of the proposed definition was to allow considerable flexibility on the part of the stakeholders in defining the boundaries of a region to best meet their identified integration opportunities. While there was no intent to generally restrict the definition to MPAs or States, the FHWA determined that regional ITS architectures should be based on an integration strategy that was developed by an MPO or State as part of its transportation planning process. Given that the final rule does not require or reference an integration strategy, the FHWA feels a need to provide more specific guidance on the definition of a region. As such, the definition of a region has been revised to indicate that the MPA should be the minimum area considered when establishing the boundaries of a region for purposes of developing a regional ITS architecture within a metropolitan area. This should not be interpreted to mean that a region must be an MPA, or no less than an MPA, but the MPA and all the agencies and jurisdictions within the MPA should be at least considered for inclusion in the process of developing a regional ITS architecture within a metropolitan area. This rule is silent on other possible limits or minimum areas for defining a region, relying on the flexible nature of this rule to accommodate those special circumstances. The FHWA also acknowledges it is possible that overlapping regions could be defined and overall regional ITS architectures be developed to meet the needs of the regions.

Other Definitions. There were 20 comments suggesting that other terms used in the NPRM be defined. These included “interoperability,” “standards,” “concept of operations,” “conceptual design,” and “integration strategy.” Several of these are no longer used in the final rule and, therefore, were not defined. Other terms, such as “interoperability” and “standards,” were determined to be common terms whose definitions did not affect the implementation of the final rule. Furthermore, language regarding standards conformity has been clarified in the body of the final rule.

Section 940.5 Policy

Twenty-eight commenters addressed the issue of consistency between the two related FHWA notices of proposed rulemaking (23 CFR parts 940 and 1410) and the Federal Transit Administration’s (FTA) notice (FTA Docket No. FTA–99–6417) on National ITS Architecture published at 65 FR 34002 on May 25, 2000. The comments revealed a lack of understanding about the relationship between the regional ITS architecture and the integration strategy proposed as part of the revisions to FHWA’s transportation planning rules. There were five comments suggesting a single DOT rule addressing how all ITS projects would meet the National ITS Architecture conformance requirements of the TEA–21 instead of an FHWA rule for highway projects and an FTA policy for transit projects. Four other comments acknowledged the need for two policies, but recommended they articulate the same process.

A final transportation planning rule is being developed on a different schedule than this rule, and comments regarding the portions of the National ITS Architecture conformity process included in the transportation planning rule will be addressed as it proceeds toward issuance. The FHWA and FTA have chosen to go forward with policies that have been developed cooperatively to implement the National ITS Architecture conformance process. This FHWA rule and the parallel FTA policy have been developed without reference to the proposed changes to the transportation planning process, including no mention of the development of an integration strategy. However, the policy statement of this rule notes a link to established transportation planning processes, as provided under 23 CFR part 450. This rule fully supports these collaborative methods for establishing transportation goals and objectives, and does not provide a mechanism for introducing projects outside of the transportation planning processes.

This final rule on National ITS Architecture conformance and the FTA policy on the same subject have been developed cooperatively and coordinated among the agencies to ensure compatible processes. Any differences between this rule and the parallel FTA policy are intended to address differences in highway and transit project development and the way the FHWA and the FTA administer projects and funds.

Fifteen commenters questioned the need for an integration strategy, and the relationship between the strategy and the regional ITS architecture. Given the fact that proposed revisions to the FHWA’s transportation planning rules are being developed according to a different schedule, this rule has been revised to remove any references to an integration strategy. Comments regarding the integration strategy will be addressed in the final transportation
planning rule, and the discussion of the regional ITS architecture in § 940.9 has been revised to clarify its content.

Section 940.7 Applicability

A few commenters noted that the proposed rule had not addressed the TEA–21 language that allows for the Secretary to authorize certain exceptions to the conformity provision. These exceptions relate to those projects designed to achieve specific research objectives or, if three stated criteria are met, to those intended to upgrade or expand an ITS system in existence on the date of enactment of the TEA–21. The legislation also included a general exemption for funds used strictly for operations and maintenance of an ITS system in existence on the date of enactment of the TEA–21.

The FHWA acknowledges this omission and has included the appropriate language in this section of the rule.

Section 940.9 Regional ITS Architecture

Several comments were received related to the way the proposed rule referred to developing regional ITS architectures. Eight comments, from State agencies and metropolitan planning organizations, supported an incremental approach to developing regional ITS architectures, starting with project ITS architectures and building them together. Four other comments, from metropolitan planning organizations and industry associations, noted that an ad hoc regional ITS architecture developed incrementally through projects would result in an architecture less robust than if there were a single, initial effort to develop it.

Also, thirteen comments from the Association of American State Highway and Transportation Officials (AASHTO) and a number of States recommended extending the time for developing regional ITS architectures, as the proposed two year implementation would be too short. Ten of the commenters preferred four years in order to acquire the necessary resources for developing regional ITS architectures.

Most commenters were in agreement with the content of the regional ITS architecture as defined in the proposed rule. However, there were 19 comments that dealt with confusion over the definition of both “conceptual design” and “concept of operations.” In addition, there were 17 other comments on the makeup of the stakeholders, involvement of the private sector, and the need and desirability of “agreements” between stakeholders.

The comments indicated confusion regarding the development of regional ITS architectures, and especially so in discussing the period of time for their development. Therefore, the final rule has clarified the time period for developing regional ITS architectures by adopting the proposed extension to four years subsequent to beginning to deploy ITS projects (§ 940.9(c)), or four years from the effective date of this rule for those areas that are currently deploying ITS projects (§ 940.9(b)). In clarifying the time for development, this rule has eliminated any references to specific methods for developing regional ITS architectures. By not prescribing any methods, the rule provides flexibility to a region in deciding how it should develop its regional ITS architecture. Guidance and information related to developing regional ITS architectures is available from FHWA Division Offices and from the ITS web site, http://www.its.dot.gov, and will be expanded to provide assistance in meeting the intent of the rule.

Both the terms “conceptual design” and “concept of operations” have been deleted from the final rule. In their stead are descriptions of the content that is expected to form the basis for a regional ITS architecture. This content has not significantly changed from that defined in the NPRM but is now contained in § 940.9(d). The level of detail required is to the architecture flow level as defined in the National ITS Architecture. The regional ITS architecture must identify how agencies, modes, and systems will interact and operate if the architecture is to fulfill the objective of promoting ITS integration within a region.

The various stakeholders for a region will vary from region to region. The list articulated in § 940.9(a) is representative only and not meant to be inclusive or exclusive. On the specific issue of public sector participation, if the private sector is deploying ITS systems in a region, instructions on providing an ITS-based service, it would be appropriate to engage them in the development of a regional ITS architecture. Because of these variations from region to region, the FHWA felt it inappropriate to attempt to define an all inclusive list of stakeholders. The group of relevant stakeholders will be a function of how the region is defined and how transportation services are provided to the public. Section 940.9(d)(4) specifies that in the development of the regional ITS architecture, it shall include “any agreements (existing or new) required for operations.” The formalization of these types of agreements is at the discretion of the region and participating stakeholders.

There were 14 comments from a broad range of organizations questioning how existing regional ITS architectures, strategic plans or ITS Early Deployment Plans would be treated under this rule. It is the intent of the FHWA that any existing ITS planning documents should be used to the extent practical to meet the requirements of this rule. If a regional ITS architecture is in place, it is up to date, and addresses all the requirements of a regional ITS architecture as described in this rule, there is no requirement to develop a “new” one. If the existing regional ITS architecture does not address all the requirements of the rule, it may be possible to update it so that it meets the regional ITS architecture requirements of this rule. What is necessary is that the end result is an architecture that meets the requirements of this rule and properly addresses the ITS deployments and integration opportunities of that region. This issue is specifically addressed in § 940.9(e) of this rule.

There were five comments related to the impact of this rule on legacy systems (i.e., ITS systems already in place) and requesting some sort of “grandfathering” for them. The language in § 940.11(g) of the final rule clarifies the grandfathering or staging aspects of the process. The final rule does not require any changes or modifications to existing systems to conform to the National ITS Architecture. It is very likely that a regional ITS architecture developed by the local agencies and other stakeholders would call for changes to legacy systems over time to support desired integration. However, such changes would not be required by the FHWA; they would be agreed upon by the appropriate stakeholders as part of the development of the regional ITS architecture.

There were 15 comments dealing with the maintenance process and status of the National ITS Architecture. Two comments suggested the need for the FHWA to formally adopt the National ITS Architecture. Four other comments also supported the formalization of a process for maintaining or updating it with the full opportunity for public input.

Conformance with the National ITS Architecture is interpreted to mean the use of the National ITS Architecture to develop a regional ITS architecture, and the subsequent adherence of all ITS projects to that regional ITS architecture. This rule requires that the National ITS Architecture be used as a resource in developing a regional ITS architecture.
As a technical resource, it is important that the National ITS Architecture be maintained and updated as necessary in response to user input or to add new user services, but formal adoption of the National ITS Architecture is not necessary. However, the FHWA recognizes the need to maintain the National ITS Architecture and to establish an open process for configuration control that includes public participation. The process currently used by the DOT to maintain the National ITS Architecture is very rigorous and involves significant public participation. That process is currently being reviewed by the DOT with the intent of establishing a configuration management process that engages the public at key stages and ensures a consensus for updating the National ITS Architecture.

Four comments suggested that this rule should not be implemented until the National ITS Architecture was complete. The National ITS Architecture will never stop evolving since there always is a potential need to regularly update it as more is learned about ITS deployment. The FHWA believes the National ITS Architecture is developed to a stage where it can be used as a resource in developing regional ITS architectures, as required by this rule.

Seventeen comments asked the FHWA to define the agency that is responsible for the development and maintenance of the regional ITS architecture; specifically MPOs and/or the States as those entities that are already responsible for the planning process. The FHWA did not define the responsibility for either creating or maintaining the regional ITS architecture to a specific entity because of the diversity of transportation agencies and their roles across the country. It is recognized that in some regions traditional State and MPO boundaries may not meet the needs of the traveling public or the transportation community. This is also why the FHWA did not rigidly define a region. The FHWA encourages MPOs and States to include the development of their regional ITS architectures as part of their transportation planning processes. However, the decision is best left to the region to determine the approach that best reflects their needs, as indicated in §940.9. It is clear that the value of a regional ITS architecture will only be realized if that architecture is maintained through time. However, in accepting Federal funds under title 23, U.S.C., the State is ultimately responsible for complying with Federal requirements, as provided in 23 U.S.C. 106 and 133.

Four commenters noted that the proposed rule did not adequately address planning for, or committing to, a defined level of operations and maintenance.

The final rule addresses this concern on two primary levels, in the development of the regional ITS architecture and the development of individual projects. Section 940.9(d)(4) specifies that in the development of the regional ITS architecture, it shall include “any agreements (existing or new) required for operations.” The formalization of these types of agreements is at the discretion of the region and participating stakeholders.

Also, relative to operations and management at a project level, §940.11(c)(7) specifies that the systems engineering analysis (required of all ITS projects) includes “procedures and resources necessary for the operations and management of the system.”

Section 940.11 Project Implementation

In addition to the comments on regional ITS architecture development noted above, the docket received 86 comments on systems engineering and project implementation. These comments revealed that the structure of the NPRM in discussing regional ITS architecture development, project systems engineering analysis, and project implementation was confusing and difficult to read.

To clarify these portions of the rule, the systems engineering and project implementation sections of the NPRM have been combined into §940.11, Project Implementation. Also, paragraphs that were in the regional ITS architecture section of the NPRM that discussed major ITS projects and the requirements for developing project level ITS architectures have been rewritten to clarify their applicability. Since these paragraphs deal with project development issues, they have been moved to §940.11(e). A definition for “project level ITS architecture” was added in §940.3 and a description of its contents provided in §940.11(e).

The docket received 33 comments regarding systems engineering and the systems engineering analysis section of the proposed rule. Most of the comments related to the definition, the process not being necessary except for very large projects, and confusion as to how these requirements relate to existing FHWA policy.

In response to the docket comments, the definition of systems engineering in §940.3 has been clarified and is more consistent with accepted practice. In order to provide consistency in the regional ITS architecture process, the systems engineering analysis detailed in §§940.11(a) through 940.11(c) must apply to all ITS projects regardless of size or budget. However, the analysis should be on a scale commensurate with project scope. To allow for the greatest flexibility at the State and local level, in §940.11(c), a minimum number of elements have been clearly identified for inclusion in the systems engineering analysis. Many of those elements are currently required as provided in 23 CFR 655.409, which this rule replaces.

Recognizing the change in some current practices this type of analysis will require, the FHWA intends to issue guidance, training, and technical support in early 2001 to help stakeholders meet the requirements of the final rule.

Fifty-three comments were submitted regarding ITS standards and interoperability tests. The commenters expressed concern about requiring the use of ITS standards and interoperability tests prematurely, the impact on legacy systems of requiring ITS standards, and confusion regarding the term “adopted by the DOT.”

In response to the comments, the FHWA has significantly modified the final rule to eliminate reference to the use of standards and interoperability tests prior to adoption in §940.11(f). Section 940.11(g) addresses the applicability of standards to legacy systems. It is not the intent of the DOT to formally adopt any standard before the standard is mature; and also, not all ITS standards should, or will, be formally adopted by the DOT. Formal adoption of a standard means that the DOT will go through the rulemaking process, including a period of public comment, for all standards that are considered candidates for adoption.

The DOT has developed a set of criteria to determine when a standard could be considered for formal adoption. These criteria include, at a minimum, the following elements:

1. The standard has been approved by a Standard Development Organization (SDO).
2. The standard has been successfully tested in real world applications as appropriate.
3. The standard has received some degree of acceptance by the community served by the standard.
4. Products exist to implement the standard.
5. There is adequate documentation to support the use of the standard.
6. There is training available in the use of the standard where applicable.
Therefore, the intent of the rule is to require the use of a standard only when those criteria have been met, and there has been a separate rulemaking on adoption of the standard. The only interoperability tests that are currently contemplated by the DOT are those associated with the Commercial Vehicle Operations (CVO) program. These tests are currently being used by States deploying CVO systems and will follow a similar set of criteria for adoption as those defined for standards.

Section 940.13 Project Administration

There were nine comments related to how conformity with the final rule would be determined, and by whom. There were 11 comments about how conformity with the regional ITS architecture would be determined, and by whom. Six comments specifically suggested methods for determining conformance, including a process similar to current Federal planning oversight procedures. Six other commenters suggested that determination be made by the MPO or State. For either case, the comments reflected a lack of clarity as to what documentation would be necessary. There were six related comments suggesting the level of documentation be commensurate with the scale of the planned ITS investments in the region.

In § 940.13 of the final rule, the FHWA has attempted to clarify the process for determining conformance. Conformance of an ITS project with a regional ITS architecture shall be made prior to authorization of funding for project construction or implementation as provided in 23 U.S.C. 106 and 133. We do not intend to create new oversight procedures beyond those provided in 23 U.S.C. 106 and 133, but in those cases where oversight and approval for ITS projects is assumed by the State, the State will be responsible for ensuring compliance with this regulation and the FHWA’s oversight will be through existing processes.

There were 14 comments concerning the documentation requirements of the proposed rule and generally suggesting they be reduced. Certainly the development of a regional ITS architecture and evidence of conformance of a specific project to that regional ITS architecture implies some level of documentation be developed. However, to allow flexibility on the part of the State or local agency in demonstrating compliance with the final rule, no specific documentation is required to be developed or submitted to the FHWA for review or approval. The FHWA recognizes the need to be able to scale the regional ITS architecture and the associated documentation to the needs of the region. Section 940.9(a) of the final rule contains specific language allowing such scaling.

Summary of Requirements

I. The Regional ITS Architecture

This final rule on the ITS Architecture and Standards requires the development of a local implementation of the National ITS Architecture referred to as a regional ITS architecture. The regional ITS architecture is tailored to meet local needs, meaning that it does not address the entire National ITS Architecture and can also address services not included in the National ITS Architecture. The regional ITS architecture shall contain a description of the region and the participating agencies and other stakeholders; the roles and responsibilities of the participating agencies and other stakeholders; any agreements needed for operation; system functional requirements; interface requirements and information exchanges with planned and existing systems; identification of applicable standards; and the sequence of projects necessary for conformance. Any changes made in a project design that impact the regional ITS architecture shall be identified and the appropriate revisions made and agreed to in the regional ITS architecture.

Any region that is currently implementing ITS projects shall have a regional ITS architecture within four years of the effective date of this rule. All other regions not currently implementing ITS projects shall have a regional ITS architecture within four years of the first ITS project for that region advancing to final design. In this context, a region is a geographical area that is based on local needs for sharing information and coordinating operational strategies among multiple projects. A region can be specified at a metropolitan, Statewide, multi-State, or corridor level. Within a metropolitan area, the metropolitan planning area should be the minimum area that is considered when establishing the boundaries of a region for purposes of developing a regional ITS architecture. A regional approach promotes integration of transportation systems. The size of the region should reflect the breadth of the integration of transportation systems.

II. Project Development

Additionally, this rule requires that all ITS projects be developed using a systems engineering analysis. All ITS projects that have not yet advanced to final design are required to conform to the system engineering requirements in § 940.11 upon the effective date of this rule. Any ITS project that has advanced to final design by the effective date of this rule is exempt from the requirements of § 940.11. When the regional ITS architecture is completed, project development will be based on the relevant portions of it which the project implements. Prior to completion of the regional ITS architecture, major ITS projects will develop project level ITS architectures that are coordinated with the development of the regional ITS architecture. ITS projects will be required to use applicable ITS standards and interoperability tests that have been officially adopted by the DOT. Where multiple standards exist, it will be the responsibility of the stakeholders to determine how best to achieve the interoperability they desire.

Rulemaking Analyses and Notices

Executive Order 12866 (Regulatory Planning and Review) and DOT Regulatory Policies and Procedures

The FHWA has determined that this action is not a significant regulatory action within the meaning of Executive Order 12866 or significant within the meaning of the Department of Transportation’s regulatory policies and procedures. It is anticipated that the economic impact of the rulemaking will be minimal. This determination is based upon preliminary and final regulatory assessments prepared for this action that indicate that the annual impact of the rule will not exceed $100 million nor will it adversely affect the economy, a sector of the economy, productivity, jobs, the environment, public health, safety, or State, local, or tribal governments. In addition, the agency has determined that these changes will not interfere with any action taken or planned by another agency and will not materially alter the budgetary impact of any entitlements, grants, user fees, or loan programs. Copies of the preliminary and final regulatory assessments are included in the docket.

Costs

The FHWA prepared a preliminary regulatory evaluation (PRE) for the NPRM and comments were solicited. That analysis estimated the total costs of this rule over 10 years to be between $38.1 million and $44.4 million (the net present value over 10 years was between $22.3 million and $31.2 million). The annual constant dollar impact was estimated to range between $3.2 million and $4.4 million. We believe that the...
cost estimates as stated in the PRE are negligible. The FHWA received only one comment in response to the PRE. That commenter, the Capital District Transportation Committee of Albany, New York suggested that our cost estimates were too low, but provided no further detail or rationale which would cause us to reconsider or increase our cost estimates in the initial regulatory evaluation.

These 10-year cost estimates set forth in the PRE included transportation planning cost increases, to MPOs ranging from $10.8 million to $13.5 million, and to States from $5.2 million to $7.8 million associated with our initial requirement to develop an ITS integration strategy that was proposed as part of the metropolitan and statewide planning rulemaking effort. The agency now plans to advance that proposed ITS integration strategy in the planning rule on a different time schedule than this final rule. Thus, the costs originally set forth in the PRE for the ITS integration strategy have been eliminated from the final cost estimate in the final regulatory evaluation (FRE) for this rule.

In the FRE, the agency estimates the cost of this rule to be between $1 million an $16 million over ten years, which are the estimated costs of this rule to implementing agencies for the development of the regional ITS architectures. These costs do not include any potential additional implementation costs for individual projects which are expected to be minimal and were extremely difficult to estimate. Thus, the costs to the industry are less than that originally estimated in the agency’s NPRM.

Benefits

In the PRE, the FHWA indicated that the non-monetary benefits derived from the proposed action included savings from the avoidance of duplicative development, reduced overall development time, and earlier detection of potential incompatibilities. In developing a final regulatory evaluation for this action, we did not denote a significant change in any of the benefits anticipated by this rule. This is so notwithstanding the fact that our planning costs for the ITS integration strategy have been eliminated from the final cost estimate. The primary benefits of this action that result from avoidance of duplicative development, reduced overall development time, and earlier detection of potential incompatibilities will remain the same.

In sum the agency believes that the option chosen in this action will be most effective at helping us to implement the requirements of section 5206(e) of the TEA–21. In developing the rule, the FHWA has sought to allow broad discretion to those entities impacted, in levels of response and approach that are appropriate to particular plans and projects, while conforming to the requirements of the TEA–21. The FHWA has considered the costs and benefits of effective implementation of ITS through careful and comprehensive planning. Based upon the information above, the agency anticipates that the economic impact associated with this rulemaking action is minimal and a full regulatory evaluation is not necessary.

Regulatory Flexibility Act

In compliance with the Regulatory Flexibility Act (5 U.S.C. 601–612), the FHWA has evaluated, through the regulatory assessment, the effects of this action on small entities and has determined that this action will not have a significant economic impact on a substantial number of small entities. Small businesses and small organizations are not subject to this rule, which applies to government entities only. Since § 940.9(a) of this rule provides for regional ITS architectures to be developed on a scale commensurate with the scope of ITS investment in the region, and § 940.11(b) provides for the ITS project systems engineering analysis to be on a scale commensurate with the project scope, compliance requirements will vary with the magnitude of the ITS requirements of the entity. Small, less complex ITS projects have correspondingly small compliance documentation requirements, thereby accommodating the interest of small government entities. Small entities, primarily transit agencies, are accommodated through these scaling provisions that impose only limited requirements on small ITS activities. For these reasons, the FHWA certifies that this action will not have a significant impact on a substantial number of small entities.

Unfunded Mandates Reform Act of 1995

This action does not impose unfunded mandates as defined by the Unfunded Mandates Reform Act of 1995 (Pub. L. 104–4, March 22, 1995, 109 Stat. 48). This rule will not result in an expenditure by State, local, and tribal governments, in the aggregate, or by the private sector, of $100 million or more in any one year.

Executive Order 13132 (Federalism)

This action has been analyzed in accordance with the principles and criteria contained in Executive Order 13132, dated August 4, 1999, and the FHWA has determined that this action does not have sufficient federalism implications to warrant the preparation of a federalism assessment. The FHWA has also determined that this action does not preempt any State law or State regulation or affect the State’s ability to discharge traditional State governmental functions.

Executive Order 12372 (Intergovernmental Review)

Catalog of Federal Domestic Assistance Program Number 20.205, Highway planning and construction. The regulations implementing Executive Order 12372 regarding intergovernmental consultation on Federal programs and activities apply to this program.

Paperwork Reduction Act of 1995

This action does not contain information collection requirements for the purposes of the Paperwork Reduction Act of 1995, 44 U.S.C. 3501–3520.

Executive Order 12988 (Civil Justice Reform)

This action meets applicable standards in sections 3(a) and 3(b)(2) of Executive Order 12988, Civil Justice Reform, to minimize litigation, eliminate ambiguity, and reduce burden.

Executive Order 13045 (Protection of Children)

We have analyzed this action under Executive Order 13045, Protection of Children from Environmental Health Risks and Safety Risks. This rule is not an economically significant rule and does not concern an environmental risk to health or safety that may disproportionately affect children.
Executive Order 12630 (Taking of Private Property)

This rule does not effect a taking of private property or otherwise have taking implications under Executive Order 12630, Government Actions and Interference with Constitutionally Protected Property Rights.

National Environmental Policy Act

The agency has analyzed this action for the purposes of the National Environmental Policy Act of 1969, as amended (42 U.S.C. 4321–4347), and has determined that this action will not have any effect on the quality of the environment.

Regulation Identification Number

A regulation identification number (RIN) is assigned to each regulatory action listed in the Unified Agenda of Federal Regulations. The Regulatory Information Service Center publishes the Unified Agenda in April and October of each year. The RIN contained in the heading of this document can be used to cross reference this proposed action with the Unified Agenda.

List of Subjects

23 CFR Part 655

Design standards, Grant programs-transportation, Highways and roads, Incorporation by reference, Signs and symbols, Traffic regulations.

23 CFR Part 940

Design standards, Grant programs-transportation, Highways and roads, Intelligent transportation systems.


Kenneth R. Wykle,
Federal Highway Administrator.

In consideration of the foregoing, the FHWA amends Chapter I of title 23, Code of Federal Regulations, as set forth below:

PART 655—[AMENDED]

1. The authority citation for part 655 continues to read as follows:

Authority: 23 U.S.C. 101(a), 104, 109(d), 114(a), 217, 315, and 402(a); 23 CFR 1.32, and 49 CFR 1.48(b).

Subpart D—[Removed and reserved]


3. Add a new subchapter K, consisting of part 940, to read as follows:

Subchapter K—Intelligent Transportation Systems

PART 940—INTELLIGENT TRANSPORTATION SYSTEM ARCHITECTURE AND STANDARDS

Sec.
940.1 Purpose.
940.3 Definitions.
940.5 Policy.
940.7 Applicability.
940.9 Regional ITS architecture.
940.11 Project implementation.
940.13 Project administration.


§ 940.1 Purpose.

This regulation provides policies and procedures for implementing section 5206(e) of the Transportation Equity Act for the 21st Century (TEA–21), Public Law 105–178, 112 Stat. 457, pertaining to conformance with the National Intelligent Transportation Systems Architecture and Standards.

§ 940.3 Definitions.

Intelligent Transportation System (ITS) means electronics, communications, or information processing used singly or in combination to improve the efficiency or safety of a surface transportation system.

ITS project means any project that in whole or in part funds the acquisition of technologies or systems of technologies that provide or significantly contribute to the provision of one or more ITS user services as defined in the National ITS Architecture.

Regional ITS architecture means a structured process for arriving at a final design of a system. The final design is selected from a number of alternatives that would accomplish the same objectives and considers the total life-cycle of the project including not only the technical merits of potential solutions but also the costs and relative value of alternatives.

§ 940.5 Policy.

ITS projects shall conform to the National ITS Architecture and standards in accordance with the requirements contained in this part. Conformance with the National ITS Architecture is interpreted to mean the use of the National ITS Architecture to develop a regional ITS architecture, and the subsequent adherence of all ITS projects to that regional ITS architecture. Development of the regional ITS architecture should be consistent with the transportation planning process for Statewide and Metropolitan Transportation Planning.

§ 940.7 Applicability.

(a) All ITS projects that are funded in whole or in part with the highway trust fund, including those on the National Highway System (NHS) and on non-NHS facilities, are subject to these provisions.

(b) The Secretary may authorize exceptions for:

(1) Projects designed to achieve specific research objectives outlined in the National ITS Program Plan under section 5205 of the TEA–21, or the Surface Transportation Research and Development Strategic Plan developed under 23 U.S.C. 508; or

(2) The upgrade or expansion of an ITS system in existence on the date of enactment of the TEA–21, if the Secretary determines that the upgrade or expansion:

(i) Would not adversely affect the goals or purposes of Subtitle C (Intelligent Transportation Systems Act of 1998) of the TEA–21; and

(ii) Is carried out before the end of the useful life of such system; and

Region is the geographical area that identifies the boundaries of the regional ITS architecture and is defined by law.
(iii) Is cost-effective as compared to alternatives that would meet the conformity requirement of this rule.

(c) These provisions do not apply to funds used for operations and maintenance of an ITS system in existence on June 9, 1998.

§ 940.9 Regional ITS architecture.

(a) A regional ITS architecture shall be developed to guide the development of ITS projects and programs and be consistent with ITS strategies and projects contained in applicable transportation plans. The National ITS Architecture shall be used as a resource in the development of the regional ITS architecture. The regional ITS architecture shall be on a scale commensurate with the scope of ITS investment in the region. Provision should be made to include participation from the following agencies, as appropriate, in the development of the regional ITS architecture: Highway agencies; public safety agencies (e.g., police, fire, emergency/medical); transit operators; Federal lands agencies; State motor carrier agencies; and other operating agencies necessary to fully address regional ITS integration.

(b) Any region that is currently implementing ITS projects shall have a regional ITS architecture by February 7, 2005.

(c) All other regions not currently implementing ITS projects shall have a regional ITS architecture within four years of the first ITS project for that region advancing to final design.

(d) The regional ITS architecture shall include, at a minimum, the following:

(1) A description of the region;

(2) Identification of participating agencies and other stakeholders;

(3) An operational concept that identifies the roles and responsibilities of participating agencies and stakeholders in the operation and implementation of the systems included in the regional ITS architecture;

(4) Any agreements (existing or new) required for operations, including at a minimum those affecting ITS project interoperability, utilization of ITS related standards, and the operation of the projects identified in the regional ITS architecture;

(5) System functional requirements;

(6) Interface requirements and information exchanges with planned and existing systems and subsystems (for example, subsystems and architecture flows as defined in the National ITS Architecture);

(7) Identification of ITS standards supporting regional and national interoperability; and

(8) The sequence of projects required for implementation.

(e) Existing regional ITS architectures that meet all of the requirements of paragraph (d) of this section shall be considered to satisfy the requirements of paragraph (a) of this section.

(f) The agencies and other stakeholders participating in the development of the regional ITS architecture shall develop and implement procedures and responsibilities for maintaining it, as needs evolve within the region.

§ 940.11 Project implementation.

(a) All ITS projects funded with highway trust funds shall be based on a systems engineering analysis.

(b) The analysis should be on a scale commensurate with the project scope.

(c) The systems engineering analysis shall include, at a minimum:

(1) Identification of portions of the regional ITS architecture being implemented (or if a regional ITS architecture does not exist, the applicable portions of the National ITS Architecture);

(2) Identification of participating agencies roles and responsibilities;

(3) Requirements definitions;

(4) Analysis of alternative system configurations and technology options to meet requirements;

(5) Procurement options;

(6) Identification of applicable ITS standards and testing procedures; and

(7) Procedures and resources necessary for operations and management of the system.

(d) Upon completion of the regional ITS architecture required in §§ 940.9(b) or 940.9(c), the final design of all ITS projects funded with highway trust funds shall accommodate the interface requirements and information exchanges as specified in the regional ITS architecture. If the final design of the ITS project is inconsistent with the regional ITS architecture, then the regional ITS architecture shall be updated as provided in the process defined in § 940.9(f) to reflect the changes.

(e) Prior to the completion of the regional ITS architecture, any major ITS project funded with highway trust funds that advances to final design shall have a project level ITS architecture that is coordinated with the development of the regional ITS architecture. The final design of the major ITS project shall accommodate the interface requirements and information exchanges as specified in this project level ITS architecture. If the project final design is inconsistent with the project level ITS architecture, then the project level ITS architecture shall be updated to reflect the changes. The project level ITS architecture is based on the results of the systems engineering analysis, and includes the following:

(1) A description of the scope of the ITS project;

(2) An operational concept that identifies the roles and responsibilities of participating agencies and stakeholders in the operation and implementation of the ITS project;

(3) Functional requirements of the ITS project;

(4) Interface requirements and information exchanges between the ITS project and other planned and existing systems and subsystems; and

(5) Identification of applicable ITS standards.

(f) All ITS projects funded with highway trust funds shall use applicable ITS standards and interoperability tests that have been officially adopted through rulemaking by the DOT.

(g) Any ITS project that has advanced to final design by February 7, 2001 is exempt from the requirements of paragraphs (d) through (f) of this section.

§ 940.13 Project administration.

(a) Prior to authorization of highway trust funds for construction or implementation of ITS projects, compliance with § 940.11 shall be demonstrated.

(b) Compliance with this part will be monitored under Federal-aid oversight procedures as provided under 23 U.S.C. 106 and 133.

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