Intelligent Transportation Systems Design Guide

Bureau of Highway Safety and Traffic Engineering

PUB 646 (4-11)

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Common Terms and Acronyms

4CIF	CCTV format, resolution = 704 x 576 pixels
ATMS	Advanced Traffic Management System
ATRWS	Automatic Truck Rollover Warning System
AWG	American Wire Gauge
BHSTE	Bureau of Highway Safety and Traffic Engineering
BIO	Bureau of Infrastructure and Operations
BOD	Bureau of Design
BPR	Bureau of Planning and Research
CCTV	Closed-Circuit Television
CIR	Committed Information Rate
CTS	Commonwealth Telecommunication Services
D1	CCTV format, resolution = 720 x 480 pixels
DMS	Dynamic Message Sign
DMZ	“De-Militarized Zone”, PennDOT server farm gateway
FHWA	Federal Highway Administration
FPS	Frames per Second
FRAD	Frame Relay Access Device
GIS	Geographic Information System
GPS	Global Positioning System
HAR	Highway Advisory Radio
ITB	Information Technology Bulletin
ITS	Intelligent Transportation System
LAN	Local Area Network
MMP	Maintenance Management Plan
MPT	Maintenance and Protection of Traffic
NEC	National Electrical Code
NTSC	National Television System Committee
O&M	Operations and Maintenance
OA	Office of Administration
PDA	Pre-Determined Amount
PennDOT	Pennsylvania Department of Transportation
PSTN	Public Switched Telephone Network
PTZ	Pan Tilt Zoom
RF	Radio Frequency
ROW	Right-of-Way
RTMC	Regional Traffic Management Center
RTMS	Remote Traffic Microwave Sensor
RWIS	Road Weather Information System
STMC	Statewide Transportation Management Center
TMC	Traffic Management Center
TMS	Traffic Management System
TS&L	Type, Size, and Location
TVSS	Transient-Voltage Surge Suppressor
USDOT	United States Department of Transportation
WAN	Wide Area Network
XHHW-2	Single copper conductor (wire)

1 Introduction

1.1 Purpose of the Guide

PennDOT Publication 646, *Intelligent Transportation Systems Design Guide* focuses on deployment guidelines and the design process for the deployment of Intelligent Transportation Systems (ITS) projects. This publication supplements PennDOT Publication 647M, *Civil and Structural Standards for Intelligent Transportation Systems.*

The purpose of this publication is to ensure the proper deployment of ITS field devices to support PennDOT transportation operations.

1.2 Intended Audience

This document is directed at all individuals involved in the planning, design, procurement and deployment of ITS devices. This may include BHSTE, BIO, BOD, District ITS staff, design consultants, and contractors.

1.3 Supporting Resources and References

Table 1-1: Pennsylvania Resources

Reference	Description
PennDOT Publication 647M, *Civil and Structural Standards for Intelligent Transportation Systems ITS-1000M Series*	To standardize the design of infrastructure elements that support Intelligent Transportation Systems (ITS). The series should be used by all Districts and their consultants for all ITS projects. ftp://ftp.dot.state.pa.us/public/PubsForms/Publications/Pub%20647M.pdf
PennDOT Publication 10A, *Design Manual Part 1A: Transportation Engineering Procedures (Dual Unit)*	The purpose of this manual is to describe the engineering procedures required to support PennDOT's project development process. Although these procedures may be used in Planning, Prioritization and Programming, or Maintenance and Operations, their primary applications are in the Design and Construction phases of project development. ftp://ftp.dot.state.pa.us/public/Bureaus/design/PUB10A/incover.pdf
PennDOT Publication 13M, *Design Manual, Part 2: Highway Design*	The purpose of this Manual is to provide its users with the current, uniform procedures and guidelines for the application and design of safe, convenient, efficient and attractive highways that are compatible with their service characteristics and that satisfy optimally the needs of highway users while maintaining the integrity of the environment. ftp://ftp.dot.state.pa.us/public/Bureaus/design/Pub13M/insidecover.pdf

Reference	Description
PennDOT Publication 14M, *Design Manual, Part 3: Plans Presentation*	The objective of this Manual is to promote uniformity in the preparation of plans by establishing the general format and presenting the detailed information which is required for each type of plan sheet required in the maintenance and construction of highway facilities. The guidance provided shall also assist the designer in avoiding errors and omissions which consequently would require excessive alterations and corrections. ftp://ftp.dot.state.pa.us./public/Bureaus/design/PUB14M/incover.pdf
Publication 15M Design Manual, Part 4: Structures	Design Manual, Part 4 is part of a series of PennDOT design manuals which have the specific objective of obtaining uniformity and establishing standard policies and procedures in the preparation of design and construction plans for highway structures. ftp://ftp.dot.state.pa.us/public/bureaus/design/bqad/pubs/Pub15M-DM4.pdf

1.4 Description of the Icons

To help guide the reader through this document, the following Icons are used to draw attention to various parts:

Key Point: Important Design Requirements/Recommendations

Resources: Additional Resources that are Available

Terminology: Definitions and Terms

2 CCTV Camera

2.1 System Purpose & Design Flow

The primary function of the Closed Circuit Television (CCTV) camera is to provide surveillance of the transportation system and enhance situational awareness. CCTVs enable Department Operations staff to perform a number of valuable monitoring, detection, verification, and response activities.

Some typical CCTV Camera uses include:

- Detecting and Verifying Incidents
- Monitoring Traffic Conditions
- Monitoring Incident Response and Clearance
- Verifying Message Displays on Dynamic Message Signs
- Assisting Emergency Responders
- Monitoring Environmental Conditions (visibility distance, wet pavements, etc.)
- Monitoring assets (Homeland Security)

To maximize the effectiveness of a CCTV camera and to reduce potential threats to driver safety, the camera type and location must be carefully considered when deploying any new camera. The design process can be simply illustrated in the following figure. First, the operational requirements of the camera must be considered. This will determine the camera type and the general camera location required to achieve those requirements. These two factors determine the mounting structure characteristics that are needed.

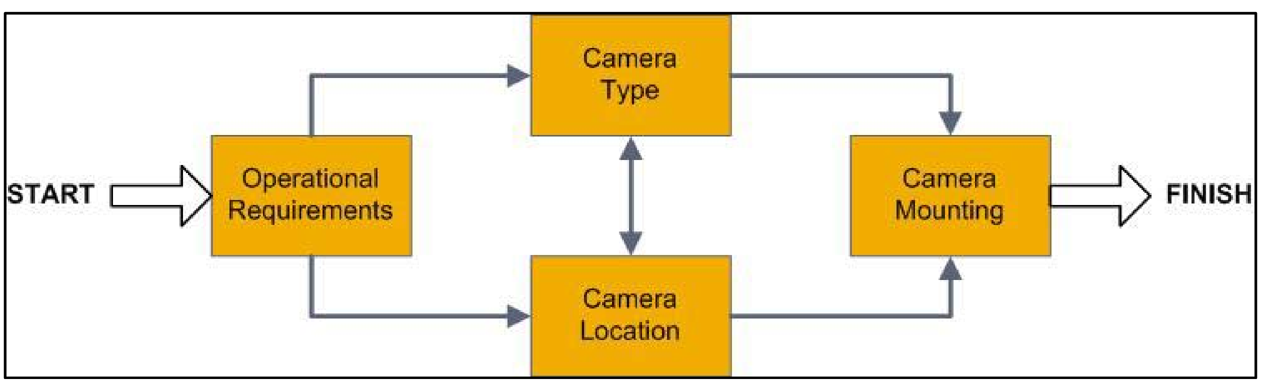


Figure 2-1: CCTV Design Flow Chart

There are several Departmental and industry standards/requirements related to CCTV. The table below highlights some of the more important ones:

Table 2-1: CCTV Standards

Criteria	Relevant Standard
• Camera Type	• PennDOT Pub 408, Section 1210 – Closed Circuit Television Camera
• Communication and Software	• National Transportation Communications for ITS Protocol (NTCIP 1203)
• Structure	• American Association of State Highway and Transportation Officials (AASHTO) • PennDOT ITS-1000M ITS standards • PennDOT ITS-1002M Structural standards
• Enclosure	• National Electrical Manufacturers Association (NEMA) TS 4 standards • PennDOT Pub 408, Section 1201 – ITS Device Enclosure

2.2 Design Considerations

The following list is intended to be a high level guide to assist ITS practitioners through the many criteria associated with a CCTV Camera design. Each section of the list corresponds to a section of this document chapter. The background, details, and specific regulations or guidance related to the design process for a camera are contained in those referenced sections.

The criteria contained in this publication must be followed when designing new CCTV cameras. It is important to note/clarify that there will be instances where all of the criteria in these guidelines cannot be met. Justification for deciding to go through with an installation, despite not being able to meet all criteria should be detailed by the designer. The goal of this process is to provide practitioners with guidance as well as providing the Department consistency with respect to camera installations.

Table 2-2 contains an overview of the design considerations contained in this chapter and an outline of the chapter in general. For a design checklist that can be used for projects, see Appendix A, Section 10.1 **CCTV Design Checklist**. The checkboxes in the right-hand column are a simple way to track whether or not the guidance in the left-hand column has been considered by the ITS practitioners during the design process.

Table 2-2: CCTV Design Considerations and Section Outline

Detection Purpose	Section 2.1
• Is this deployment consistent with "needs" outlined in a Concept of Operations or Regional Operations Plan? • Is this deployment consistent with the ITS architecture?	
Location/Placement Guidelines	**Section 2.3**
• Has the camera location been chosen/designed with consideration to maximizing visibility? • Has a site for the camera been chosen that considers the available utilities and the cost/constraints associated with connection to those utilities? • Has the site been chosen with consideration to protecting the camera structure and ensuring that it will last; without undue maintenance necessary to the structure and the surrounding site? • Has a site been chosen that makes the best use of the operational needs of a CCTV camera system (e.g. Incident Management)? • Has a site been chosen that satisfies safety requirements for personnel performing maintenance on the system? • Has the site been chosen so that it will minimize maintenance costs (e.g. there is sufficient shoulder to park a bucket truck without the need for a full lane closure and significant MPT)?	
CCTV Type	**Section 2.4**
• Is the camera type (external vs. dome) appropriate for the desired location? • Does the District require the camera to be compatible with a legacy analog system?	
Camera Mount	**Section 2.5**
• Have Department standards ITS-1000M and ITS-1002M been followed in the design of the mount/structure?	
Enclosure	**Section 2.6**
• Is an enclosure required at this location? • Can personnel safely access the enclosure? • Is the enclosure located within 150 feet of the camera? • Is the enclosure mounted on the camera pole or on an existing structure (where possible)? • Does the location and orientation provide adequate protection for the enclosure? • Has a concrete maintainer's pad been provided at the enclosure's main door?	

Power Requirements	Section 8.1.1
• Have the power requirements for the camera and all of the system components been determined?	
Power Availability	**Section 8.1.2**
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the camera site? • Have Step-Up/Step-Down requirement calculations been performed? • Have the metering options been determined?	
Power Conditioning	**Section 8.2**
• Have the UPS and power back-up options been determined and accounted for?	
Communication	**Section 9**
• Have the communication requirements for the camera been determined? • Has an appropriate communication infrastructure been located and confirmed within a reasonable proximity to the site? • If there are multiple communication options, have the pros/cons been studied? • If using public communications infrastructure, has service been coordinated with PennDOT BIO and the District?	
Environmental	
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	

2.3 Location/Placement Guidelines

The selection of CCTV camera locations is based on the operational and maintenance requirements. The desired coverage will often dictate the general camera locations. This should be a primary design consideration. Local topography will also play a major role.

Camera locations should provide a clear line of site with minimal obstructions. The considerations outlined in Table 2-3 below, should be taken into account when selecting the site and placement of the camera.

Table 2-3: Camera Site Selection and Placement Considerations

Camera Site Selection and Placement Considerations	
Visibility	• Cameras in low light conditions, such as tunnels, should be located so that the main view is away from bright light • Near horizontal curves, install on outside of curve • Near vertical curves, install at the crest • At the intersection of two major routes or an interchange, place CCTV so that secondary roads can also be monitored • The blind spot created from the pole should be oriented at a location non-critical to viewing
Utility Availability	• Consider proximity to power and communications • If fiber optic communication is available, try to place the camera on the same side of the roadway to eliminate lateral crossings (this is secondary to visibility regulations)
Safety and Device Protection	• Protect CCTV structure with guiderail inside the clear zone, but consider lateral deflection and maintenance vehicle access • Medians are not the preferred location, but wide medians may be considered if suitable roadside locations are not available • To reduce site erosion, reduce construction costs, and provide longer device structure life, avoid locating the structure on sections that have a fill slope of greater than one vertical to three horizontal
Operational Considerations	• Install at locations with recurring congestion and other high volume areas • Install at locations known to have adverse weather conditions • Install at locations with recurring crashes • If possible, position cameras to view nearby Dynamic Message Signs (DMS) for message verification • Large interchanges of two major freeways may require more than one camera to obtain all desired views of roadways and ramps • If possible, avoid mounting onto bridge structures due to the potential of vibration affecting the image

Camera Site Selection and Placement Considerations	
Maintenance Considerations	• Where possible, the CCTV should be located such that a maintenance vehicle can park in the immediate vicinity, without necessitating a lane closure or blocking traffic, when possible. • A concrete maintainer pad in front of the enclosure opening should be provided per Pub 647M • The CCTV cabinet should be mounted away from traffic so that the maintainer is facing traffic when looking at the cabinet. This will increase the life of the filter as well as the safety of the maintainer

2.3.1 Urban Vs. Rural

In urban areas, full camera coverage is considered full build. Full camera coverage of a roadway results in CCTV camera placement such that an operator can view and monitor the entire corridor, with no breaks. Full build out is warranted on certain roadways in urban areas, given the high usage of the roadway. In order to provide full and continuous coverage of a roadway (subject to the operational requirements), cameras should be placed no more than 1 mile apart depending on the curvature of the roadway.

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

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

- Urban Area – Urban places of 5,000 or more population and urbanized areas as designated by the Bureau of Census

- Small Urban Area – Places having a population of 5,000 or more, not in an urbanized area

- Rural – The area outside the boundaries of small urban & urbanized areas.

Roadway designations can be found at BPR's website and in their 2009 Highway Statistics.

When possible utilize a camera equipped van or bucket truck to validate CCTV placements prior to installation.

2.4 Camera Type

Most of the desired CCTV camera features are standard with the common commercial products. A camera may be chosen that meets the Department's Publication 408, Section 1200 – ITS Specifications

- Section 1210 – Closed Circuit Television Camera
- Section 1210 – Video Encoder/Decoder

The following features related to camera type must be considered as part of the design process:

- Dome vs. Barrel mount
- Analog vs. IP

Note that barrel mount cameras are not included in the Pub 408 ITS Specifications. Barrel cameras should be used on a case-by-case basis, and for very specific applications. A special provision must be written for any barrel camera used in a project.

2.4.1 Pan & Tilt vs. Fixed

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 90 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. The speed of the pan/tilt mechanism determines the *rate* of camera coverage, while the horizontal and vertical camera movements determine the coverage *area*.

Dome enclosed systems provide much higher P/T speeds. Dome systems also have much more range than external units, having the ability to look straight down. It should be noted that Dome cameras are "horizon limited" and cannot look up at the sky or up a nearby steep hill very well. However, unless the camera is to be placed in very hilly terrain, this is not a major drawback for roadway traffic monitoring.

Barrel cameras should only be considered for installations that only focus on one view, and in locations where the camera will not have to fight strong wind loads such as tunnels and long underpasses. Dome cameras are the preferred camera type.

2.4.2 Analog vs. IP

The Departmental 408 Specifications contain two camera types; one which transmits video in IP format only and one which is a dual IP/Analog camera.

New CCTV camera deployments should always be of the IP type, except in the case where the District **requires** the camera to be analog-compatible.

The need to deploy analog cameras is typically due to the District still maintaining legacy infrastructure that contains a significant number of older analog devices or cannot accommodate IP signals.

2.5 Selection of Camera Mounting Type

The overriding factor in determining a CCTV camera location is the site's fitness for performing the operational role that it is designed for (see Section 2.3). If all other factors are equal, the ITS practitioner may possibly have more than one option on the type of camera mount to design. The three possible choices are:

- Pole-mounted
- On an existing Sign or Structure, like a bridge (requires coordination with the PennDOT Bridge Unit)
- Inside a Tunnel or on a Wall

The most prevalent structure for CCTV cameras is a hollow steel pole. Design standards for a CCTV pole can be found in the following Departmental documents:

Resources

ITS-1000M for the Department's ITS standards
ITS-1002M for the Department's Structural standards

2.5.1 Camera Lowering Device

The practice of installing pole-mounted CCTV cameras in combination with camera-lowering system is not required, but should be considered for all CCTV installations. The inclusion of a camera-lowering system will increase the overall cost of the system, but allows for easier access to the camera; in many cases eliminating the need to use a bucket truck or similar vehicle for maintenance, and reduce the need for lane-closures.

For a pole mounted cabinet, do not place the cabinet on the same side as the hand hole for a camera lowering winch or under the camera to be lowered.

Standard Specifications for a CCTV Camera Lowering Device can be found in Publication 408 – ITS Device Special Provisions:

Resources

Section 1210 - Closed Circuit Television Camera

2.6 ITS Enclosure Placement

When the CCTV system includes devices that will be designed, constructed, and maintained, as Department-owned assets, the enclosure and its associated components must be included in the design process.

Design criteria for a suitable ITS enclosure location includes the following:

- When possible, the enclosure for the CCTV controller should be pole-mounted on the CCTV pole or existing structures in order to maximize cost savings.
- In locations where the pole is difficult to access, the enclosure may be ground-mounted at a more convenient location with easier access, such as adjacent to a frontage road.
  - The enclosure is to be placed in the safest possible location, generally along the right shoulder.
  - A ground-mounted enclosure should be located at a minimum distance from the barrier, based on the design and type of barrier used. See standard drawings for appropriate minimums.
  - The enclosure should be oriented so that the maintainer is facing the roadway, while performing maintenance at the cabinet location.

  - The enclosure should be at a level where the maintainer doesn't need a step ladder to perform maintenance at the cabinet location.
  - The enclosure should be located less than 100 feet from the camera. If further, then equalizing amplifiers for video should be provided. If the camera is IP, the absolute maximum distance is 300 feet based on restrictions of the communications cable.
- A leveled concrete pad should be provided at the front of the enclosure for the maintenance worker to stand on while accessing the enclosure.
- Where possible, there should be adequate and safe parking conditions present for parking of a maintenance vehicle in the vicinity of the enclosure. Where this is not possible, locate the camera where it is accessible by on-foot maintenance personnel.
- See manufacturer's specifications to determine the maximum distance between the enclosure and the field device it services.

When it comes to designing the enclosure, there is no "standard" size. There is a wide variety of component manufacturers to choose from and this will usually impact the enclosure interior space requirements. In some case, co-located ITS devices may also share the same enclosure. This will further influence the design of the enclosure size.

Standard Specifications for an ITS enclosure can be found in Departmental publication 408 – ITS Device Special Provisions:

Resources

Section 1201 – Intelligent Transportation Systems Device Enclosure

3 DYNAMIC MESSAGE SIGNS

3.1 System Purpose & Design Flow

The primary function of the Dynamic Message Sign (DMS) is to provide traveler information. The nature of this information is varied, but the goal is to disseminate roadway condition information to travelers so that they can make informed decisions regarding their intended trip and/or route.

DMS must be utilized in accordance with the DMS Operating Guidelines document published by PennDOT. Some typical DMS uses include notifying travelers of:

- Full Road Closure
- Lane Closures (Incident, Maintenance/Construction, Events, etc.)
- Weather/Road Conditions
- AMBER Alert
- Special Events
- Travel Times (Automated, Real-time)
- Future Road Work
- Scheduled Safety Messages (Formerly Public Service Announcements)
- Sign Testing

Resources

DMS Operating Guidelines

To maximize the effectiveness of a DMS and to reduce potential threats to driver safety, the sign type, placement, and the supporting structure must all be carefully considered when designing and deploying any new sign. First, the operational requirements of what purpose the sign will satisfy must be considered. This will determine the general location and the type of sign. These operational requirements and the location will determine the required support structure. The design process can be simply illustrated in Figure 3-1.

There are several Departmental and industry standards/requirements related to DMS. Table 3-1 highlights some of the more important ones.

Figure 3-1: DMS Design Flow Chart

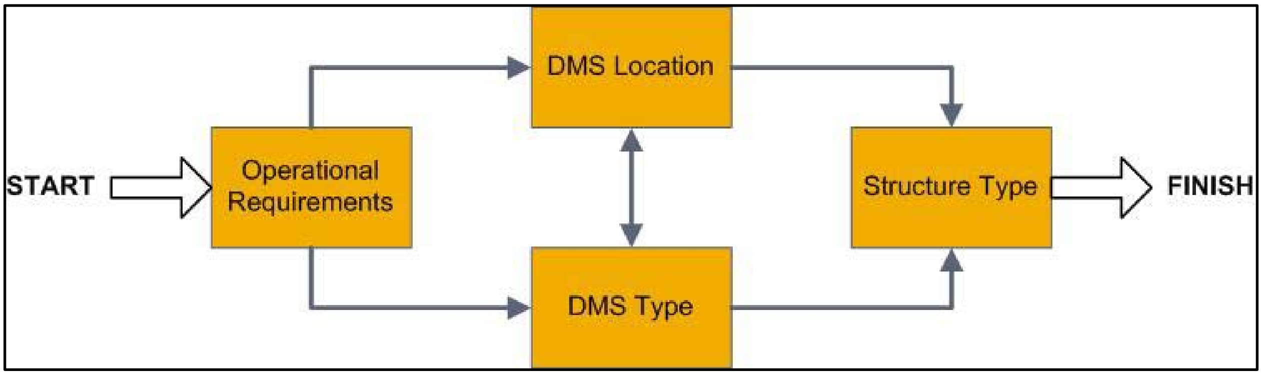


Table 3-1: DMS Standards

Criteria	Relevant Standard
• Sign Type	• Manual on Uniform Traffic Control Devices (MUTCD) most current version adopted by the Department. See Section 2.L for DMS-specific guidance. • PennDOT Pub 408, Section 1230 – Dynamic Message Signs
• Communication and Software	• National Transportation Communications for ITS Protocol (NTCIP 1203)
• Structure	• American Association of State Highway and Transportation Officials (AASHTO) • PennDOT ITS-1000M ITS standards • PennDOT ITS-1002M Structural standards
• Enclosure	• National Electrical Manufacturers Association (NEMA) TS 4 standards • PennDOT Pub 408, Section 1201 – ITS Device Enclosure

3.2 Design Considerations

The following list is intended to be a high level guide to assist ITS practitioners through the many criteria associated with a DMS design. Each section of the list corresponds to a section of this document chapter. The background, details, and specific regulations or guidance related to the design process for a DMS are contained in those referenced sections.

The criteria contained in this publication must be followed when designing new DMS. It is important to note/clarify that there will be instances where all of the criteria in these guidelines cannot be met. Justification for deciding to go through with an installation, despite not being able to meet all criteria should be detailed by the designer. The goal of this process is to provide practitioners with guidance as well as providing the Department consistency with respect to DMS installations.

Table 3-2 contains an overview of the design considerations contained in this chapter and an outline of the chapter in general. For a design checklist that can be used for projects, see Appendix A, Section 10.2 **DMS Design Checklist**. The checkboxes in the right-hand column are a simple way to track whether or not the guidance in the left-hand column has been considered by the ITS practitioners during the design process.

Table 3-2: DMS Design Considerations

Pre-Design Planning	Section 3.1
• Is this deployment consistent with "needs" outlined in a Concept of Operations or Regional Operations Plan? • Is this deployment consistent with the ITS architecture?	
Longitudinal Placement	**Section 3.3.1**
• Is the DMS visible and un-obscured? • Is the DMS placed sufficiently in-advance of any interchanges that would be used for diversions? • Is the DMS properly spaced away from existing guide signs?	
Lateral Placement	**Section 3.3.2**
• Is the DMS structure located beyond the clear zone or protected by a suitable safety barrier? • Has the lateral offset of the DMS been accounted-for when calculating the length of the Reading and Decision Zone?	
Vertical Placement	**Section 3.3.3**
• Is the approaching segment of roadway relatively flat (between 0-4% vertical grade)	
Sign Matrix Type	**Section 3.4.1**
• Has a sign matrix type been chosen that is consistent with the visibility and message requirements of the roadway being deployed on?	
Sign Viewing Angle	**Section 3.4.2**
• Has a sign viewing angle been chosen that complements the roadway alignment and the DMS structure?	
Sign Access	**Section 3.4.3**
• Are there any traffic, environmental, or safety factors that warrant a specific type of sign access?	
Structure	**Section 3.5**
• Have visibility, road speed/volume, right-of-way, and maintenance/cost issues all been considered when selecting a type of sign structure? • Is there sufficient vertical clearance for the sign and the structure?	

Enclosure	Section 3.6
• Can personnel safely access the enclosure? • Is the enclosure located within a reasonable distance of the sign? • Is the sign face visible from the enclosure location? • Does the location and orientation provide adequate protection for the enclosure?	
Power Requirements	Section 8.1.1
• Have the power requirements for the DMS and all of the system components been determined?	
Power Availability	Section 8.1.2
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the DMS site? • Have Step-Up/Step-Down requirement calculations been performed? Have the metering options been determined?	
Power Conditioning	Section 8.2
• Have the UPS and power back-up requirements been determined and accounted for?	
Communication	Section 9
• Have the communication requirements for the DMS been determined? • Has an appropriate communication infrastructure been located and confirmed within a reasonable proximity to the site? • If there are multiple communication options, have the pros/cons been studied? • If using public communications infrastructure, has service been coordinated with PennDOT BIO and the District?	
Environmental	
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	

3.3 Location/Placement Guidelines

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

- Operating speed of the roadway;
- Presence and characteristics of any vertical curves affecting sight distance;
- Presence of horizontal curves and obstructions such as trees or bridge abutments that constrain sight distance to the DMS around the curve;
- Location of the DMS relative to the position of the sun (for daytime conditions);

- Presence, number, and information on static guide signs in the vicinity; and
- Frequency of fog that may reduce visibility of the sign.

3.3.1 Longitudinal Placement

The main considerations related to longitudinal placement of a DMS are to minimize obstructions of and by the DMS, provide for the maximum visibility of the DMS message, and allow the driver ample time in which to read, process, and react to the message.

The approach to a sign can be divided into 3 "zones." (See Figure 3-2)

- Detection Zone
- Reading and Decision Zone
- Out-of-Vision Zone

Detection Zone: At typical (65 mph) highway speeds, the sign board should be visible to the approaching driver from 1000'-2000' away. The visibility distance should also be increased if the DMS is placed at an offset from the traveling lane, per Figure 3-3.

Reading and Decision Zone: As a general rule, the message panels on a highway-deployed DMS usually contain room for 3 lines of 12-21 characters each (see Section 3.4.1).

- For deployment on roadways with speed limits under 55 mph, the reading and decision zone should be minimum of 800'.

- For deployments on roadways with speed limits greater than 55 mph, the reading and decision zone should be minimum of 1000' or greater.

- Individual characters of 12" in height can be seen from ~650 feet under normal conditions.

- Individual characters of 18" in height can be seen from ~1100 feet under normal conditions.

Drivers need approximately one second per word to read and comprehend a message. Travelling at 65 mph, this translates into roughly time enough to read and comprehend a 10-word message. The character height, cone of vision and lateral placement must all be considered when determining the placement of the sign to meet the sight distance requirements.

Out-of-Vision Zone: Once the driver gets close to the sign, they will not be able to read the message. The distance is determined by the viewing angle (Section 3.4.2) of the sign, the structure that the sign is placed on (Section 3.5) and the lateral placement of the sign (Section 3.3.2).

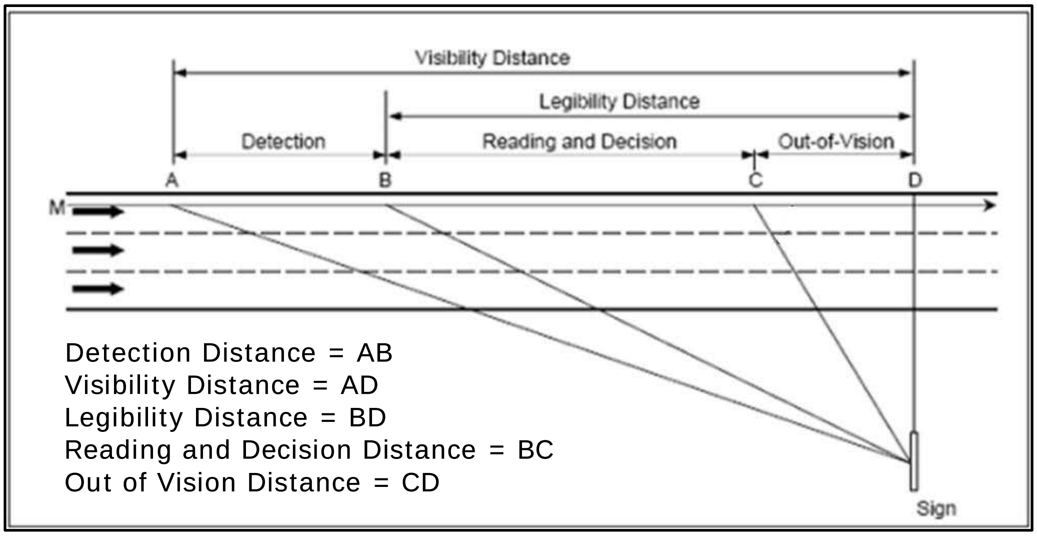


Figure 3-2: DMS Visibility

Table 3-3: DMS Longitudinal Placement Guidance

Criteria	Guidance
• Visibility	• location of the sign must provide a detection distance to drivers of at least 800’, and optimally 1000’-1200’ • on freeways/expressways, should be placed at least 800’-1000’ from a static directional sign • should be placed on straight sections of roadway, where/when possible • if the sign must be located on a curve, should be angled towards the roadway
• Reaction Time	• in **sequence**, 2 DMS should be placed no less than 1000’ apart; optimally a half mile or more • should be placed a minimum of 1000’ away from a **lane merge or expansion** • should be placed 1 to 4 miles in advance (no closer than 1 mile) of an **alternate route or major decision point** • should not be placed within close proximity of a **signalized intersection**
• Cost	• should be placed as close to **existing communications and power** to minimize costs • should avoid locating on sections that have a **fill slope** of greater than one vertical to three horizontal (to reduce site erosion, reduce construction costs, provide longer device structure life)

Table 3-4: DMS Sight Distance vs. Speed Limit vs. Roadway Type

Legibility Distance Requirements	Freeway	Limited Access Arterial	Major Arterial
Less than 45 MPH	N/A	650’	650’
45MPH to 55 MPH	850’	850’	850’
Greater than 55 MPH	1000’ or more	1000’ or more	N/A

3.3.2 Lateral Placement

National standards regarding lateral placement of signs must be followed when designing DMS. The U.S. Department of Transportation, Federal Highway Administration’s guidelines are found in the MUTCD.

Resources

Manual on Uniform Traffic Control Devices for Streets and Highways, 2009 Edition, Section 2A.19 Lateral Offset

The DMS structure must be placed far enough behind guiderail to comply with the minimum clearances values of the guiderail. Refer to the safety specifications of the particular guiderail present at the site or the guiderail planned to be installed. Refer to Design Manual 2, Chapter 12 for more information on guiderail.

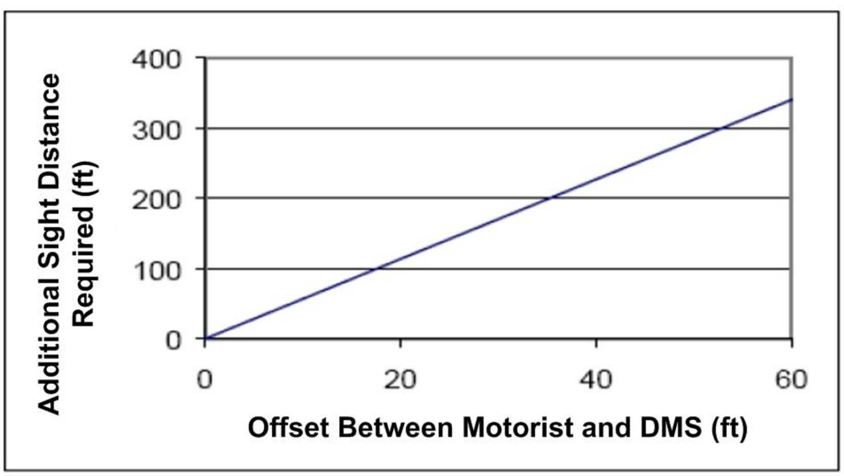


Figure 3-3: Lateral Offset vs. Required Sight Distance

The offset of the DMS (horizontal distance from the sign as a function of travel lane) will require additional sight distance to clearly view and react to the sign. Figure 3-3 provides a rough guide of the additional distance that must be factored into the longitudinal (Section 3.3.1) sign placement.

Table 3-5: DMS Offset Guidance

Criteria	Guidance
• All Signs	• all roadside DMS must be placed outside the clear zone or shielded with a crashworthy **barrier** within the clear zone • the distance between the center of a DMS and the driver's forward **line of vision** (offset) must be factored into the DMS placement • for roadways with a speed limit of 65 mph, the center of the DMS should be no more than 30 lateral feet from the driver's forward **line of vision**

3.3.3 Vertical Placement

A roadway's vertical alignment impacts the visibility of the DMS. If there are a limited number of potential locations available, a slight upward grade is desirable.

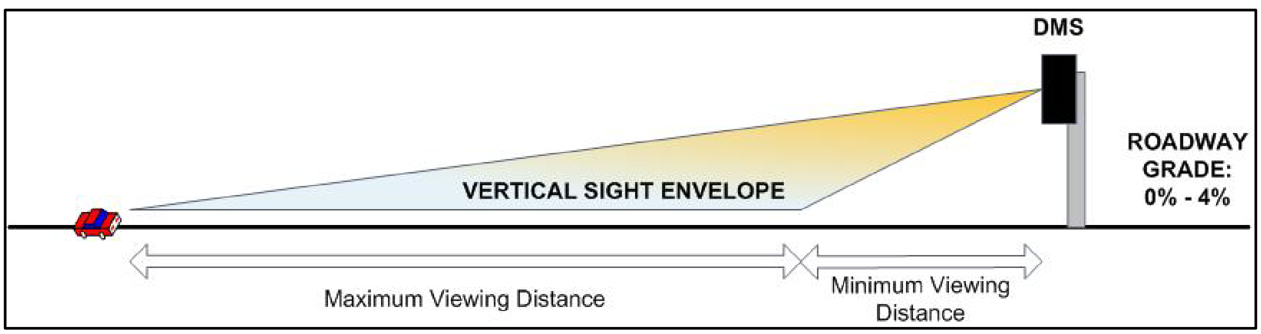


Figure 3-4: DMS Site Envelope

Table 3-6: DMS Grade Guidance

Criteria	Guidance
• All Signs	• Where possible, should be placed on roadway segments that are as flat as possible (**grade** of < 1%). Signs may be placed on segments with up to 4% grade. • should NOT be placed on roadway segments that have a **grade** of 4% or more (this may be waived if sign is placed on positive grade immediately following a similar negative grade. In these situations, expanded cones of vision should be considered to compensate for the reduction of visibility distance caused by the grade)

3.4 Selection of Sign Type

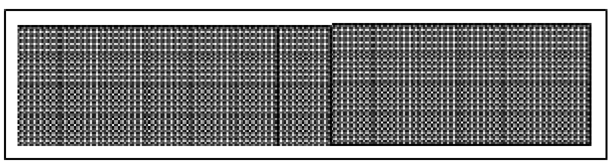
The selection of the sign type, the configuration of the display, and the technology employed all have direct or indirect impacts on the visibility of the message that will be displayed on the DMS.

3.4.1 Matrix Characteristics

DMS display characters and symbols in a matrix format, which are generally designed in one of the following three patterns:

- Character Matrix
- Line Matrix
- Full Matrix

The Department's preferred option, and the one designated in the Publication 408 Specifications (Section 1230 – Dynamic Message Signs) is Full Matrix. Full matrix DMS displays will become increasingly important, as the use of graphics and symbols become more accepted and utilized. In this format, the entire display consists of continuous matrix of pixels, as shown below.



Varying matrix types are acceptable on a case-by-case basis, but are discouraged. If a line or character matrix configuration is used, a special provision would have to be used, or a standard item modified.

The industry-standard DMS matrix technology is:

- **Light-Emitting Diode (LED) Signs.** Light-emitting diodes (LEDs) are semiconductors that emit light when current is applied. Typically, several individual LEDs are "clustered" together in order to create each pixel. LEDs have the added benefit of being able to display signs in full color with the appropriate LED type. The reliability of LED lamps is very high.

Table 3-7: DMS Display Recommendations

Criteria	Recommendation
• General	• **character height** must be between 10.6" and 18" • sign should be limited to three **lines of text** • each **line of text** should have between 11 (arterial or local road) and 21 characters (freeway/interstate/expressway)
• On Freeways	• **character height** should be 18" • a minimum of 11 **characters per line** should be provided
• All Signs	• **photocell** to automatically adjust illumination intensity of display to the ambient light

3.4.2 Viewing Angle

Viewing angle is an important aspect and depends upon the mounting location of the DMS and the curvature of the roadway. There are three standard angles available from DMS manufacturers: 15 degrees, 30 degrees, and 70 degrees. The 30 degree viewing angle is typical; however Table 3-7is a guide for utilizing each. The Pub 408 specifications require a minimum viewing angle of 15 degrees. Signs with varying viewing angles can be procured using the appropriate item number, or by modifying the standard provision.

Table 3-8: DMS Placement

Viewing Angle	Recommendation
• 15 degrees	• overhead placement and on straight lengths of roadways
• 30 degrees	• roadside placement and on slightly curved lengths of roadways
• 70 degrees	• wide highways and on curved lengths of roadway

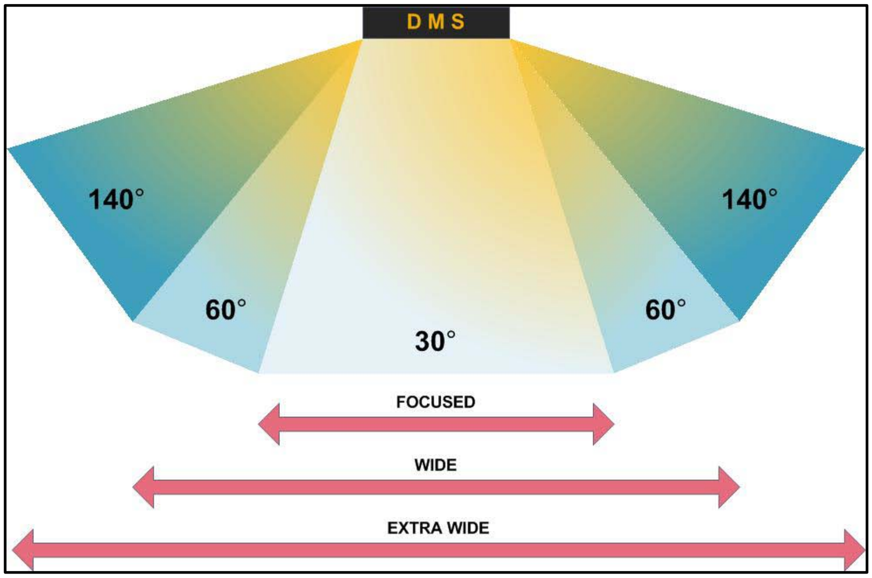


Figure 3-5: DMS Viewing Angles

3.4.3 Sign Access

The Department does not mandate the type of maintenance access of signs. However, rear-access signs are extremely difficult to access given the existing standard drawings for DMS structures. What follows is a brief examination of the pros/cons of each type.

Figure 3-6: DMS Maintenance Access

Table 3-9: DMS Access Types

Access Type	Pros	Cons	Other Considerations
Rear Access	• Smaller and lighter sign allows for a smaller structure	• Sign mounted overhead might require a lane closure • Existing PennDOT structural standards make maintenance on rear access signs very difficult	• A bucket truck is typically used to access the sign • Consider installing catwalk to avoid need for bucket truck and lane closures
Walk-In	• Provides safe environment for worker over live traffic	• Highest in installed and recurring costs	• Catwalk or platform required to access the DMS
Front Access	• Smaller and lighter sign allows for a smaller structure	• Sign mounted overhead might require a lane closure	• A bucket truck is typically used to access the sign • Consider installing catwalk to avoid need for bucket truck and lane closures

3.5 Selection of Structure

The three types of permanent structures that PennDOT allows for mounting DMS are center-mount, overhead or "span," and cantilever.

Center-mount | Overhead | Cantilever

Figure 3-7: DMS Structure Types

The lateral placement guidelines in section 3.3.2 and the nature of the roadway are the two main factors in determining the type of structure that the DMS should be mounted on. In very general terms, the wider the roadway and/or the more lanes, the greater likelihood that the sign will need to be placed on a structure that spans the roadway itself.

Table 3-10: DMS Mounting Recommendations

Roadway Type	Recommendation
• roadways with 1-2 lanes in a single direction	• roadside **center-mount** signs
• roadways with 3-4 lanes in a single direction	• full-span or mid-span, **overhead signs** or **cantilevered signs**

Table 3-11: DMS Support Type Comparison

Support Type	Pros	Cons	Other Considerations
Center-mount	• Best benefit-to-cost • Easy to maintain • Lower structural cost	• Visibility can be an issue on tangent sections • Visibility can be an issue if truck volumes are high	• **This is the Department preferred option** • Can be used best if located on outside of curve or on tangent sections • Can be used on any roadway type
Overhead	• Best for visibility	• Highest in cost • Requires more preventative maintenance than off-set DMS	• Good alternative if limited ROW available • Can be used on any roadway type • Utilize on high volume roadways
Cantilever	• Less expensive than overhead • Alternative if center-mount or full-span cannot be installed	• Structural issues, including failures, have occurred in some states • Visibility can be an issue on tangent sections • Visibility can be an issue if truck volumes are high	• Alternative if limited ROW • Can be used on any roadway type • Requires a submittal to and approval by Chief Bridge Engineer in order to be considered. The submittal is to include site justification.
Portable	• Good **temporary** alternative	• Smaller display • More susceptible to damage during snow removal activities • Typically requires the most preventative maintenance	• Suitable for construction activities and temporary emergency measure

The number of lanes, the speed characteristics, and the available ROW determine the placement and structure type of the DMS.

Portable DMS should NOT be considered as an acceptable long-term substitution for permanent DMS. Portables should only be deployed as temporary installations.

3.5.1 Structural Design Guidance

The following outline contains the information which shall be submitted for each DMS sign structure. The outline contains aspects of the DMS design required by the PennDOT Bureau of Design's Bridge Quality Assurance Division (BQAD), The Department's sign structure computer program, SIGN, shall be used for all structure types. All design calculations, plans, and details shall be in accordance with the ITS Standard Drawings (Publication 647M), as well as the applicable BC-740M's and BD-640M's standard drawings. Each DMS structure will be assigned its own S-number.

The Department's order of preference for DMS support structure types is as follows:

1. Center-mount
2. Overhead truss (4 post - 4 chord)
3. Cantilever

Cantilever support structures supporting DMS require written justification and Chief Bridge Engineer approval at the TS&L stage. Cantilever support structures are only permitted when it can be demonstrated that a Center-mount or an Overhead truss is not feasible.

<u>Design Calculations shall include:</u>

- List of Design Assumptions
  - Sign weight, dimensions, and eccentricity
  - Any non-standard loadings
  - Fatigue Importance Category
  - Design wind speed (assumed to be 80 mph in SIGN program)
- SIGN Program Output
  - Verify combined stress ratios (CSR) for all members are ≤ 1.0
  - Select appropriate fatigue details (depending on structure type) and verify corresponding CSR's are ≤ 1.0
- Foundation Design
  - One test boring shall be completed at each DMS foundation location. Where exceptions are granted and no borings are completed, use worst-case soil conditions found in the standard drawings. District Geotechnical Unit must approve the procedure and assumptions for designing the foundations.
  - SIGN program shall be used for spread footings
  - COM624 or L-Pile analysis shall be used for drilled shafts (caissons)
- Additional calculations may be required, which are not provided by the SIGN structure program, if the design criteria specified in the ITS standard drawings is not met. The following list of items that may need calculations is not all-inclusive, and may vary by structure type and details;
  - Post/Base Plate connection

- Base Plate Design
- Anchor Bolt design
- Chord Splices
- Bolted connections
- Ladder connections
- Miscellaneous weld checks
- Catwalk loading and connections

Note: The standard drawings establish minimum plate, bolt, weld sizes, etc. The SIGN program and additional calculations may require using larger plate, bolt, weld sizes, etc.

<u>Design Plans shall include:</u>

- 'General Notes' sheet
- Regarding DMS cabinet and connection, the manufacturer is to provide a signed and sealed certification letter. Ensure the 10th bullet under 'Notes to Designer' from ITS-1003M, sheet 1, is included on the design plans.
- Drawing sheets shall show, as a minimum, the applicable views and details shown on the ITS, BD, and BC standard drawings
- Provide panel connection details and notes 2 and 4 from ITS-1003M, sheet 7
- Include complete connection details with weld symbols
- Unique S-number, provided by District Bridge Unit
- Standalone drawing package is required for each DMS structure. Multiple structures being presented without detail sheet is not acceptable.

3.6 ITS Enclosure Placement

When the DMS system includes devices that will be designed, constructed, and maintained, as Department-owned assets, the enclosure and its associated components must be included in the design process.

Design criteria for a suitable ITS enclosure location includes the following:

- The enclosure should be ground-mounted, approximately 100 feet upstream of the DMS.
    - A ground-mounted enclosure should be located at a minimum distance from the barrier, based on the design and type of barrier used. See standard drawings for appropriate minimums.

  - o The enclosure should be oriented so that the maintainer is facing the roadway, while performing maintenance at the cabinet location.
- If no suitable location is available for the enclosure to be ground-mounted, it may be pole-mounted on the DMS (or other existing structure) in order to maximize cost savings or eliminate ROW takes.
- A concrete pad should be provided at the front of the enclosure for the maintenance worker to stand on while accessing the enclosure.
- Where possible, there should be adequate and safe parking conditions present for parking of a maintenance vehicle in the vicinity of the enclosure.
- See manufacturer's specifications to determine the maximum distance between the enclosure and the field device it services.

Standard Specifications for an ITS enclosure can be found in Departmental publication 408 – ITS Device Special Provisions:

Resources

Section 1201 – Intelligent Transportation Systems Device Enclosure

4 HIGHWAY ADVISORY RADIO

4.1 System Purpose & Design Flow

The primary function of the HAR is to provide traveler information. The nature of this information is varied, but the goal is to disseminate roadway condition information to travelers so that they can make informed decisions regarding their intended trip and/or route.

Some typical HAR uses include notifying travelers of:

- Incidents and Roadway/Lane Closures
- Adverse Conditions
- Construction and Maintenance Operations
- Amber Alerts
- Homeland Security Issues
- Scheduled Safety Messages
- Special Event Conditions

To maximize the effectiveness of a HAR and to reduce potential threats to driver safety, placement must be carefully considered when designing and deploying any new HAR system. The design process can be simply illustrated in the following figure. First, the design must satisfy the system purpose established in the operational requirements. For example, deploying the HAR to serve an interchange or along a corridor affects components of the design. After this, the most important design consideration is the correct placement of the transmission structure and the HAR signs.

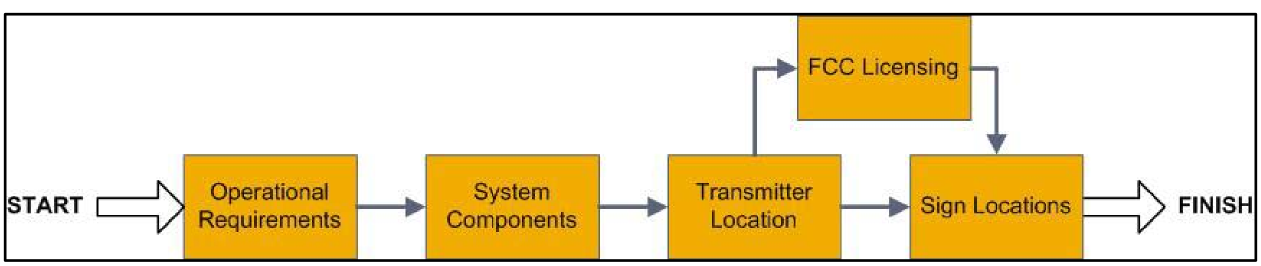


Figure 4-1: HAR Design Flow Chart

There are several Departmental and industry standards/requirements related to HAR. Table 4-1 highlights these standards.

Table 4-1: HAR Standards

Criteria	Guidance
• Sign	• Manual on Uniform Traffic Control Devices (MUTCD) most current version adopted by the Department, Chapter 4L (Flashing Beacon Signs) • Pub 408 – Section 1220 – Highway Advisory Radio System
• Transmitter	• Pub 408 – Section 1220 – Highway Advisory Radio System
• Structure	• American Association of State Highway and Transportation Officials (AASHTO)
• Enclosure	• National Electrical Manufacturers Association (NEMA) TS 4 standards • Pub 408 – Section 1201 – Intelligent Transportation Systems Device Enclosure

4.2 Design Considerations

The following list is intended to be a high level guide to assist ITS practitioners through the many criteria associated with a HAR design. Each section of the list corresponds to a section of this document chapter. The background, details, and specific regulations or guidance related to the design process for a HAR are contained in those referenced sections.

The criteria contained in this publication must be followed when designing new HAR. It is important to note/clarify however, that there will be instances where all of the criteria in these guidelines cannot be met. Justification for deciding to go through with an installation, despite not being able to meet all criteria should be detailed by the designer. The goal of this process is to provide practitioners with guidance as well as providing the Department consistency with respect to HAR installations.

Table 4-2 contains an overview of the design considerations contained in this chapter and an outline of the chapter in general. For a design checklist that can be used for projects, see Appendix A, Section 10.3 **HAR Design Checklist**. The checkboxes in the right-hand column are a simple way to track whether or not the guidance in the left-hand column has been considered by the ITS practitioners during the design process.

Table 4-2: HAR Design Considerations and Section Outline

Pre-Design Planning	Section 4.1
• Is this deployment consistent with "needs" outlined in a Concept of Operations or Regional Operations Plan? • Is this deployment consistent with the ITS architecture?	
Control Software	**Section 4.3.3**
• Is the HAR compatible with the TMC device control software?	
Site Selection	**Section 4.4**
• Are there any adjacent existing HAR systems, and if so, has coordination taken place with them? • Has a frequency search taken place? • Has an onsite listening survey been performed? • Has reception of the NOAA All-Hazards Alert System been verified? • If in an urban setting, have existing traveler information stations (e.g. AM news radio) been considered when justifying the new HAR placement?	
Transmitter Location	**Section 4.4.1**
• Is the potential transmitter site free of significant vertical (25' or higher) obstructions? • Is power (120VAC) and communication (telephone) service available at the site? • Is there sufficient open ground (at least 40' x 40') for the cabinet and antenna installation? • If there are adjacent HAR transmitters, has message synchronization been built into the design?	
Beacon Sign Location	**Section 4.4.2**
• Have MUTCD sign standards been followed? • Are the signs visible and unobstructed? • Is the sign placed such that a motorist is entering the proposed broadcast range of the HAR transmitter? • Does the location of the sign permit the traveler to safely tune and then react to the message? • Are the signs placed sufficiently in-advance of any interchanges that serve detour routes? • Is it possible to collocate the sign/beacon with an existing CCTV camera for the purpose of visual verification?	
Licensing and Permits	**Section 4.5**
• Has consideration been given to other HAR transmitters (not adjacent to the new site) along a particular route so that the same frequency can be used?	

ITS Enclosure (applies to both the transmitter location and the beacon location(s))	Section 4.6
• Can personnel safely access the enclosure? • Is the enclosure located within 150 feet of the device? • Does the location and orientation provide adequate protection for the enclosure?	
Power Requirements	**Section 8.1.1**
• Have the power requirements for the HAR and all of the system components been determined?	
Power Availability	**Section 8.1.2**
• Have the power requirements for all of the system components been determined? • Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the detector site? • Have Step-Up/Step-Down requirement calculations been performed where necessary? • Have the metering options been determined?	
Power Conditioning	**Section 8.2**
• Have the UPS and power back-up options been determined and accounted for?	
Communications	**Section 9**
• Have the communication requirements for the HAR been determined? • For wired communication, has an appropriate source been located and confirmed within a reasonable proximity to the site? • For cellular communication, has the required signal strength been verified at the site? • If there are multiple communication options, have the pros/cons been studied? • If using public communications infrastructure, has service been coordinated with PennDOT BIO and the District?	
Environmental	
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	

4.3 The HAR System

The HAR system consists of three basic components:

- the device control software (located at the TMC)
- a transmitter and antenna assembly
- roadside signs

When an operator at the controlling agency activates the HAR system, a signal is sent to the HAR transmission tower, which then begins to broadcast either a custom or a “canned” message along the pre-designated frequency. The sign/beacon assembly contains a receiver which receives this same broadcast and activates the flashing beacons, alerting drivers that there is a message. The driver then tunes their car radio to the frequency posted on the sign to listen to the traveler advisory/warning.

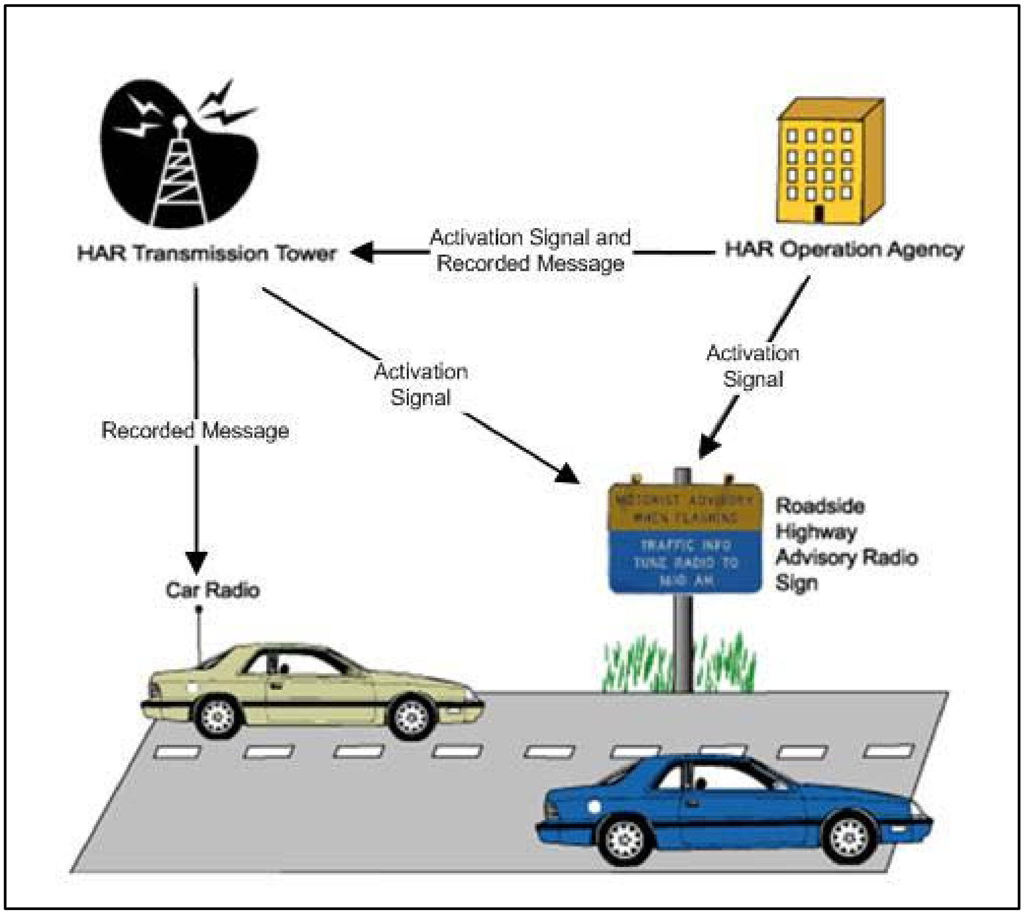


Figure 4-2: HAR System Model

4.3.1 HAR Transmitter

The transmitter site setup typically consists of the following equipment:

Figure 4-3: HAR Antenna

- Pole: the HAR antenna and control cabinet must be installed on a 30-foot (minimum height) wooden utility pole. The pole must be in accordance with HAR system manufacturer's specification and Pub 408.
- Antenna: The antenna is center or top loaded vertical featuring a low-loss embedded, weatherproof loading coil. The antenna system includes a ground plane consisting of #8 non-insulated copper conductors placed in a horizontal plane radiating from the center of the antenna, a minimum of 100 feet in radius, and at approximately equal angles from each other.
- Antenna Cabinet: The cabinet is an anodized aluminum, weatherproof enclosure. The cabinet should be lockable using contractor supplied construction cores and keys.
- AM Transmitter: The Transmitter is located in the control cabinet. The amplitude modulated transmitter must be FCC type approved.
- Voice Storage Unit: Voice Storage unit is located in the control cabinet. The voice storage unit shall digitally store messages. The unit should be equipped with dual tone multi frequency (DTMF) control capability where other communications are not utilized. With the limited availability of the RC-200 Receivers, this will be less of a requirement in the future. Industry vendors are moving forward with a different type of receiver that will allow for bi-directional communications, but no longer utilizes DTMF tones.
- Digital Communications Controller: Required for all digital communications to the HAR Transmitter (cellular, Ethernet over fiber, etc.). Not necessary with POTS connections.
- GPS Synchronization Unit: Utilized to synchronize adjacent HAR systems to accommodate corridor-wide broadcasts using 2 or more transmitters.
- Weather Receiver Module: Receives weather condition reports directly from the National Oceanic and Atmospheric Administration.
- Relay Panel and Power Supply: Relay panel and power supply are located in the control cabinet. The power supply must be capable of operating on 120 volts AC with an output of 12 volts.

There are a number of options available for HAR transmission:

- 10-Watt AM Transmission (FCC License Required)
- Digital Highway Advisory Radio (FCC License Required)
- Low-Power AM Transmission (No FCC License Required)
- Low-Power FM Transmission (FCC License Required)

The most common method, and the one currently prevalent in Pennsylvania, is the 10-Watt AM transmission. **In the interest of standardization, new HAR deployments should utilize this transmission method.**

The maximum broadcast range, operating under ideal conditions (no buildings, flat terrain, etc.) is usually six to ten miles in diameter. Actual broadcast distance, for HAR currently deployed, is in the range of three to five miles in diameter. This is highly dependent on topography, atmospheric conditions, and the time of day.

4.3.2 HAR Beacon Signs

HAR signs direct motorists to tune to the HAR broadcast frequency when beacons above the sign are flashing. HAR signs are typically located on major roadways and the approaches to major freeway interchanges, thus giving the motorist ample warning to avoid an incident or closure.

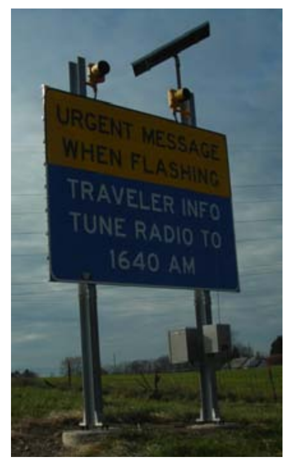


Figure 4-4: HAR Beacon

Flashing beacons and advisory signs are required at any new HAR system installation where a DMS cannot be utilized to alert motorists to tune into the HAR transmitter. However, beacons and signs are encouraged for all locations, despite the presence of DMS, to allow the DMS to disseminate other travel information not provided in an HAR broadcast.

The entire sign/beacon assembly consists of the following components:

- <u>Sign</u>: The Sign must comply with MUTCD standards and be mounted on breakaway posts.
- <u>External Illumination and Flashing Beacons</u>: These are activated, either remotely or from the sign when there is a HAR broadcast to be heard. All beacons should be 12” amber LED.

- Flashing Unit: Controls the flashing of the beacons, which should be between 50-60 flashes per minute.
- Antenna and Mount (for radio controlled signs): Use a 3 element beam antenna fastened to a sign post with a mast mount.
- Control Cabinet: The control cabinet is a rain proof, lockable enclosure, anodized aluminum, with a hinged door, accessible from ground level.
- Transmitter/Receiver: The transmitter/receiver is located in the control cabinet and must be capable of transmitting at the frequency licensed by the FCC.
- Relay Panel and Power Supply: The relay panel and power supply are located in the control cabinet.
- Key Switch: The key switch allows for control at the HAR sign and is mounted below the sign on a sign post. The key switch has three positions: “manual on” for control of the beacons at the HAR sign, “off” to turn the signs, beacons, and equipment off, and “auto on” to remotely control the sign.

4.3.3 HAR Control Software

Most PennDOT Traffic Management Centers (TMCs) currently utilize the DR2000™ Platinum HAR control software. For the purposes of statewide standardization, it is required that any new HAR deployments be compatible with the existing software.

4.4 HAR Site Selection

Correctly locating the HAR system components is the key to its success. There are six steps that must be followed. They are:

Step 1: Coordinate with adjacent systems
If there are existing HAR in the deployment area, coordinate the design and deployment of the new HAR with these other systems, even if they are located in adjacent Districts or States. This can be done in one of two ways depending on the location of the device. The first option is to utilize a GPS synchronization unit within the HAR rack that coordinates the message between two or more transmitters. This allows a seamless transmission of the message when going from the coverage area of one transmitter to another. The second option is to turn down the broadcast range of the transmitter by decreasing the power of each transmitter. This will allow for each transmitter to play a different message without an overlap area in which neither of the messages can be distinguished when tuning into the radio station.

Step 2: Conduct a frequency search

Develop a list of AM frequencies that are available. Consider what frequencies are currently utilized within the District, and in neighboring Districts along the same route. In order to maintain consistency for drivers, determine if these frequencies can be used on the proposed device. This should be written into the Contract; for the Contractor to verify the available AM frequencies, using site survey equipment.

Step 3: Survey onsite listening

Survey the highway where listening is required with an automobile digital AM radio tuned to the candidate frequencies from Step 1. Monitor all the candidate frequencies throughout the listening area at least once during daylight hours and at least once after dark. Again, this should be performed by the Contractor so that the responsibility of obtaining the correct frequency is theirs. The Contractor should provide the Department a list of available frequencies at the site location, and the Department can direct the Contractor which frequency to obtain the license for.

Step 4: Choose a general location for coverage

Find the approximate geographic center of the desired listening area. The HAR signal will propagate to a radius of 2-5 miles from this point in all directions (highly dependent on the terrain and topography). If this coverage does not encompass the highways that require coverage, consider the possibility of adding repeater stations. Consider where the system signs will be placed to announce to motorists entering the area that the signal is available.

Step 5: Determine the desired NOAA All-Hazards Alert System notification coverage

Verify reception of a National Weather Service channel (162.400-162.550 MHz) at the desired location. See coverage areas online at this NOAA web link: http//www.nws.noaa.gov/nwr/usframes.html.

Step 6: Choose a specific antenna location

See specific site guidance below in Section 4.4.1.

4.4.1 Transmitter Locating Considerations

For best transmission coverage, the immediate location should be free of tall buildings, trees, terrain features, lighting, power and communication poles and towers, overpasses, and highway signs. Make certain that 120VAC power and communications are available at the site and that there is a 40'-by-40' area of open ground for cabinet and antenna installation where possible. The preferred location is within an interchange loop or infield.

Table 4-3: HAR Transmitter Site Guidance

Criteria	Guidance
• Site obstructions	• provide a 50' radius clear zone around the antenna • should be on the highest ground possible to aid in reception of the transmission • transmitter site should be free of objects that exceed 25' (approximately 2 stories)
• Interchanges	• preferred sites for deployment; taking advantage of existing utilities and ROW • an opportunity to provide coverage on two roadways (highway and arterial) with one transmitter
• Adjacent transmitters	• important to avoid overlaps so that conflicting messages are not transmitted • GPS Synchronization Units can be utilized to synchronize messages on overlapping HAR frequencies to avoid conflicting messages • should be placed as close as possible, so that there is no significant gap in coverage

4.4.2 Sign/Beacon Siting Considerations

Strategic placement of the signs announcing the HAR is a key factor to its success. If signs are positioned poorly in relation to the transmitter radio waves, motorists are likely to think the station is not working and might be tempted to tune out, missing crucial information.

Table 4-4: HAR Sign/Beacon Site Guidance

Criteria	Guidance
• Activation signal	• preliminary design/investigation of proposed sign sites must include a signal strength test (if wireless communication being used)
• Sign visibility	• signs should be placed on straight sections of roadway where possible • should be placed at least 800' from other static or dynamic signs or other visual obstructions
• Sign Placement	• Should be located as a motorist is entering the broadcast range of the HAR transmitter. • should be located far enough from the alternate route to give the motorist time to locate the radio channel (15-20 seconds), listen to message twice (approx. 120 seconds), and divert to alternate route • the distance from sign to alternate route on a 55 mph freeway should be a minimum of 1 ½ to 2 miles, if the coverage area will allow this • the motorist should not have to take their attention from a difficult stretch of roadway (sharp curves, merges, etc.) to tune their radio to the HAR frequency
• Device collocation	• where possible, design a HAR sign within sight of an existing (or planned) CCTV camera that is able to visually confirm the status of the flashing beacons • not necessary, if designing the HAR system to have bi-directional communications with the TMC

4.4.3 Urban Siting Considerations

Prior to deploying HAR in urban areas, the designer should consider two factors; Channel availability, and existing traveler information providers.

- Availability of useable, clear channels that provide reasonable radio coverage free of interference: The designer should take care to determine that no adjacent frequencies interfere with the desired frequency broadcast. The selected frequency should encounter as little interference as possible from existing stations. This may be more difficult in urban areas due to the number of radio frequencies already being utilized by private media.
- Existing, private radio traveler information providers: If numerous private traveler information stations exist, the usefulness of an additional radio source may be minimal. Designer should determine the number of existing stations in the area that are providing traveler information at regular intervals and determine if the HAR is still necessary. Even if many traveler information stations exist, HAR are still effective tools for disseminating real-time, site specific information that can be tailored by the Department to meet the needs of roadway users.

4.5 Licensing and Permits

A FCC RF (radio-frequency) license is issued specifically for the RF band, RF transmission level, related antenna type, and location (including height). A FCC RF license is therefore required for each HAR application, including additions based on RF bands used in existing HARs.

Traditionally, the choice of a HAR RF band has been left to the system supplier because HAR system suppliers are typically more familiar with the process of FCC RF license acquisition. Note, however, the following considerations:

- The RF band at 1640 KHz AM is used for all Pennsylvania Turnpike Commission (PTC) HARs throughout the turnpike toll-way system. The use of this RF band must not be used to avoid interference with the PTC HAR system.
- FCC license for RF bands at or near the bottom and top ends of the AM radio band is usually easier to obtain as these are commercially least desirable. However, avoid accepting RF band outside of the standard AM frequency range (520 KHz to 1610 KHz) because not all AM radios used in vehicles have the “extended” AM range (below 520 KHz, and between 1610 KHz to 1710 KHz). HAR broadcast at 1680 KHz is for

example useless for many travelers as this frequency band is not available on most car radios.

- Where existing HARs are deployed along a corridor, give preference to the same RF band used in the existing system so related HAR signs along the same road are uniform.
- If possible, standardize a frequency along an entire route (e.g. I-80). Coordination with adjacent Districts may be necessary.
- FCC licensing is typically completed by the Contractor during construction, as the FCC will only issue a permanent license once the HAR transmitter is fully constructed. The FCC may issue a temporary license for a 3 month period before issuing a permanent license.

4.6 ITS Enclosure Placement

When the HAR system includes devices that will be designed, constructed, and maintained, as Department-owned assets, the enclosure and its associated components must be included in the design process.

Design criteria for a suitable ITS enclosure location includes the following:

- The enclosure for the HAR controller should be pole-mounted on the antenna pole.
- The enclosure for the beacon should be mounted on the sign structure.
- The enclosure should be oriented so that the maintainer is facing the roadway, while performing maintenance at the cabinet location.
- If the enclosure is located on a slope, a concrete pad should be provided at the front of the enclosure for the maintenance worker to stand on while accessing the enclosure.
- Where possible, there should be adequate and safe parking conditions present for parking of a maintenance vehicle in the vicinity of the enclosure.
- See manufacturer's specifications to determine the maximum distance between the enclosure and the field device it services.

Standard Specifications for an ITS enclosure can be found in Departmental publication 408 – ITS Device Special Provisions:

Resources

Section 1201 – Intelligent Transportation Systems Device Enclosure

5 VEHICLE DETECTION SYSTEMS

5.1 System Purpose & Design Flow

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

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

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

To design a detection location, consideration must be paid to: detector purpose and system needs; selecting the appropriate technology; and deployment criteria such as structure type and orientation of the sensor. The design process of a vehicle detection system is illustrated in the following diagram:

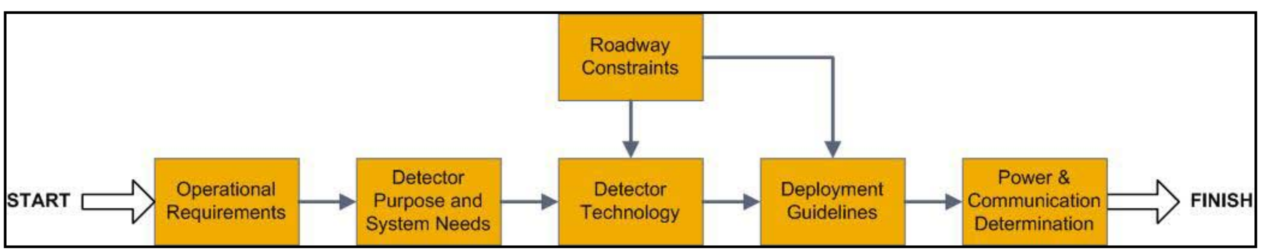


Figure 5-1: Detector Design Process

5.2 Design Considerations

The following list is intended to be a high level guide to assist ITS practitioners through the many criteria associated with a Vehicle Detection System (VDS) design. Each section of the list corresponds to a section of this document chapter. The background, details, and specific regulations or guidance related to the design process for a VDS are contained in those referenced sections.

The criteria contained in this publication must be followed when designing new VDS. It is important to note/clarify however, that there will be instances where all of the criteria in these guidelines cannot be met. Justification for deciding to go through with an installation, despite not being able to meet all criteria should be detailed by the designer. The goal of this process is to provide practitioners with guidance as well as providing the Department consistency with respect to VDS installations.

Table 5-1 contains an overview of the design considerations contained in this chapter and an outline of the chapter in general. For a design checklist that can be used for projects, see Appendix A, Section 10.4 **Vehicle Detector Design Checklist**. The checkboxes in the right-hand column are a simple way to track whether or not the guidance in the left-hand column has been considered by the ITS practitioners during the design process.

Table 5-1: Vehicle Detection Design Considerations

Detection Purpose	Section 5.1
• Is this deployment consistent with "needs" outlined in a Concept of Operations or Regional Operations Plan? • Is this deployment consistent with the ITS architecture?	
System Needs	**Section 5.4**
• Does the detector deployment satisfy the precision considerations established in the system needs? • Does the detector deployment satisfy the spacing considerations established in the system needs? • Does the detector deployment satisfy the accessibility considerations established in the system needs?	
Detector Technology Selection	**Section 5.5**
• Does the detector technology satisfy the accuracy, accessibility, and cost requirements established in the system needs?	
Deployment Guidelines	**Section 5.6**
• Does the detector deployment take steps to minimize new structures and collocate devices where possible? • Does the detector deployment include sufficient detector coverage to satisfy system needs?	
Enclosure	**Section 5.7**
• Is an enclosure required at this location? • Can personnel safely access the enclosure? • Is the enclosure located within 150 feet of the detector? • Is the enclosure mounted on an existing structure (where possible)? • Does the location and orientation provide adequate protection? • Has a maintainer's pad been provided at the enclosure's main door?	

Power Requirements	Section 8.1.1
• Have the power requirements for the detector and all of the system components been determined?	
Power Availability	**Section 8.1.2**
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the detector site? • Have Step-Up/Step-Down requirement calculations been performed? • Have the metering options been determined?	
Power Conditioning	**Section 8.2**
• Have the UPS and power back-up options been determined and accounted for?	
Communication	**Section 9**
• Have the communication requirements for the detector been determined? • Has an appropriate communication source been located and confirmed within a reasonable proximity to the site? • If there are multiple communication options, have the pros/cons been studied? • If using public communications infrastructure, has service been coordinated with PennDOT BIO and the District?	
Environmental	
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	

5.3 Detection Purpose

For operations purposes, vehicle detectors are typically deployed for either data collection or incident detection purposes. The need for the detection system must stem from the user needs established in the Concept of Operations or Regional Operation Plan for the project, and the functionality of the system must come directly from the project's Operational Requirements document.

5.3.1 Data Collection

Vehicle detectors for data collection are deployed in two methods:

- Single Point Detection – Deployed at specific points along the roadway to gather and store data such as vehicle volumes, speeds and occupancy. This is the most common VDS deployment.
- Roadway Corridor Detection – Deployed along whole corridors to gather data such as vehicle volumes and speeds. These data are used

to generate maps or other graphical representations of corridor speeds, typically called speed maps.

5.3.2 Incident Detection

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

5.4 System Needs

This section identifies and prioritizes the needs of the Data Collection and Incident Detection systems as they relate to vehicle detectors. The detector technology and the placement of the detectors must satisfy these needs. The comprehensive list of system needs is as follows:

- Location Precision
- Comprehensive Data Capabilities
- Detector Accuracy
- Detector Spacing
- Detector Cost
- Detector Accessibility

These six needs are prioritized for each system below. One (1) is most important and Six (6) is least important, comparatively. The system needs identified in this section should be used as considerations when selecting the appropriate detector technology in the next section.

5.4.1 Single Point Data Collection

The goal of single point data collection is to obtain highly accurate data at specific points of interest on the roadway. Primary considerations for the placement of point data collection systems are, in order of importance:

1. <u>Location Precision</u> – Position the detectors at the location of interest. Varying from the intended location may leave the detector useless.
2. <u>Comprehensive Data Capabilities</u> – The detector must be capable of collecting the appropriate data. The data type requirements are defined in the concept of operations and/or the operational

requirements. Comprehensive data are usually required for point detectors, including vehicle classification.

3. Accuracy – Detectors are used to gather historical and operational data, which requires a high level of accuracy. Use a time-proven technology that is known to provide trustworthy data within a 7% error.
4. Cost – Minimize the overall cost of installation by collocating sensors on existing structures where possible, and minimizing the number of sensors required in order to collect the data.
5. Accessibility – Detectors should be accessible for maintenance and installation purposes. Avoid the use of technologies that require lane-shutdown to perform maintenance.
6. Spacing – Single point configuration. Spacing is not applicable.

5.4.2 Corridor Data Collection

The goal of corridor data collection is typically to obtain speeds along the corridor, and provide this data to motorists as real-time traveler information. Note that this configuration is similar to Incident Detection (5.4.3), with the exception that the detector spacing requirement is not as stringent. Primary considerations for the placement of corridor data collection detectors are:

1. Spacing – Corridor data collection devices should be spaced from 0.5 to 1.5 miles apart. Spacing of 1 mile or less is optimal to effectively capture corridor characteristics. A greater quantity of devices increases the amount of corridor data.
2. Cost – Because multiple detectors are necessary for corridor detection, the cost of the system can quickly escalate. Choose detector types, locations and communication methods that minimize the overall cost of the system. Collocate detectors on existing structures where possible to minimize the need for new structures.
3. Accessibility – Accessibility of the device for maintenance and repair purposes is of high importance, especially when many devices are necessary for a system. Inaccessible devices lead to higher costs and the potential need to close lanes to perform maintenance, which increases the potential for disruption of traffic.
4. Accuracy – Speed data must be accurate within a range of approximately 5mph. Accuracy of other data such as volume and occupancy is secondary to the accuracy of speed data unless the

detector is to be used as a point detector as well as part of a corridor detection system.

5. Comprehensive Data Capabilities – For corridor data collection, only speed and volume are typically necessary.
6. Location Precision – Precision is secondary to detector spacing. The exact location of the detector is not of high importance, unless the detector is to be used as a point detector as well as part of a corridor detection system.

When placing corridor detectors to generate corridor speed data, spacing is the key design consideration. Optimal spacing is every 1 mile or less, but a range of 0.5-1.5 miles can be used.

5.4.3 Incident Detection

The purpose of an incident detection system along a corridor is to provide an automated alert to the TMC and response personnel of potential roadway incidents. The system uses an algorithm that considers speed, volume and occupancy to determine the presence of an incident. Note that this configuration can also serve in a dual function. The system can also perform Corridor Data Collection (Section 5.4.2). Primary considerations for the placement of incident detectors are:

1. Spacing – Incident detectors should be spaced every 0.5 miles or less in order to be effective. The quantity and frequency of detectors correlate with the effectiveness of the overall system. Detector spacing is paramount.
2. Cost – Because multiple detectors are necessary for incident detection, the cost of the system can quickly escalate. Choose detector types, locations and communication methods that minimize the overall cost of the system. Collocate detectors on existing structures (e.g. CCTV poles) where possible to minimize the need for new structures, provided the integrity of 0.5 mile detector spacing remains intact.
3. Accessibility – Accessibility of the device for maintenance and repair purposes is of high importance, especially when many devices are necessary for a system. Inaccessible devices lead to higher costs and the potential need to close lanes to perform maintenance, which increases the potential for disruption of traffic.
4. Comprehensive Data Capabilities – For incident detection, only speed and volume are typically required.

5. Accuracy – Speed data must be accurate within a range of approximately 5mph. Accuracy of other data such as volume and occupancy must provide data within a 10% accuracy level.
6. Location Precision – Precision is secondary to detector spacing. The exact location of the detector is not of high importance, provided the integrity of 0.5 mile detector spacing remains intact.

When placing incident detectors, spacing is the key design consideration. Spacing of 0.5 miles or less is necessary for an effective system.

5.5 Select Vehicle Detection Technology

Use the system needs identified in the previous chapter to select the appropriate technology. The three detector technologies predominantly used for vehicle detection are – inductive loops, radar, and video image detection system. Table 5-2 displays how each of the technologies fulfills the system needs.

Table 5-2 should be used as a starting point for selecting the appropriate detector technology. Table 5-3 displays additional design considerations and advantages vs. disadvantages for each system.

The designer should use the System Needs Table 5-2, and Table 5-3 to determine the appropriate detection technology for the proposed system. The remainder of this chapter identifies design considerations and guidelines for each detection system.

Microwave/Radar is the preferred detector type by the Department.

Table 5-2: Detector Type Advantages and Disadvantages

Detection Technology	Design Advantages	Design Disadvantages
Induction Loop	• Mature, tested technology • Provides an array of data: volume, presence, occupancy, gap, and speed • Is not affected by inclement weather	• Installation requires pavement cut • Cannot perform maintenance without interrupting traffic • Can reduce pavement life • Loops are required for every travel lane, increasing costs and complexity • Requires software system to interpret data feed • May require series of detectors to provide vehicle classification capabilities
Microwave/Radar	• Widely used and tested technology • Non-intrusive technology – no pavement work is necessary • Multiple lanes can be detected using a single detector • Can be mounted to existing structures • Low installation costs	• Can be affected by rainy/snowy conditions • May require calibration after storm events • Obstructions such as guiderail, jersey barriers, roadway cut sections and retaining walls may decrease accuracy • Requires setback from roadway – may cause problems in situations where ROW is limited • Requires software system to interpret data feed
Video Image Processing	• Widely used and tested technology • Non-intrusive technology – no pavement work is necessary • Can provide video images of the roadway to a TMC	• When mounted above roadway, traffic may be interrupted during installation • Can be affected by shadows and fog • Requires processing technology that can be expensive • Requires software system to interpret data feed

Table 5-3: Detector Technology Options

Detector Technology	Structure Type	Available Data	Accuracy	Accessibility	System Cost
Inductive Loop	None (In-pavement)	-Speed -Volume -Occupancy -Classification (special software and additional detectors required)	Moderate-High	Difficult/ Intrusive	Low (single point) – High (multiple lanes)
Microwave /Radar	35' Pole or Existing Structure	-Speed -Volume -Occupancy (special software required) -Classification (special software required)	Moderate	Easy	Low-Moderate
Video Image Detection Systems (VIDS)	35' Pole or Existing Structure	-Speed -Volume -Occupancy -Classification	Moderate-High	Moderate	Moderate-high (Also must consider additional hardware/software needed)

5.5.1 Alternative and Future Detection Technologies

In addition to the three current/standard methods (outlined above) that are predominantly being used for vehicle detection, there are many up-coming emergent technologies. Some that warrant mention are:

- Bluetooth: the vast amount of Bluetooth-enabled technology out there (cell phones, PDAs, MP3 players, laptops, GPS, car radios, cameras, games, etc.) offers an opportunity for the Department to use the proximity signals in these devices as a detection method. For more information, see Section 7.4 and 7.5.3.

- Probe Data: probe data is collected by 3rd party entities, processed, and resold for the purchasing agencies to utilize for congestion detection and/or travel times. In many cases, this is a cost-savings method of detection, as the Department does not actually shoulder the cost of deploying a lot of new infrastructure. For more information, see Section 7.4 and 7.5.4.

- In-pavement Wireless: a minimally intrusive yet powerful method of collecting vehicle volume, occupancy, speed, and queue length data. Small sensors installed in the pavement detect vehicles passing over, collect the vehicular data, and send that information through a wireless connection to a roadside access and/or repeater point.

5.6 Deployment Guidelines

This section identifies deployment guidelines and criteria for each detector technology. The designer should use this section as a guide for deployment of the detector or system of detectors.

5.6.1 Loop Detection

Loop vehicle detectors consist of a metal loop buried several inches beneath the pavement surface of the roadway, and are positioned in the center of the traveling lanes. They utilize electrical induction from vehicles passing over the loop to detect vehicle presence.

For specifics concerning the size and placement of the loop within the travel lane, the Designer should adhere to the guidelines for "Short non-Sequential Loops" in Chapter 16 of PennDOT Pub 149 – Traffic Signal Design Handbook.

For additional guidance concerning the placement of the loop within the travel lane, the Designer should refer to Chapter 4 – Traffic Signals – Construction, Section 4.8.6.9 (Detectors) of PennDOT Pub 46 – Traffic Signal Design Handbook.

5.6.2 Microwave/Radar Detection

Radar detectors consist of a sensor mounted on the side of the road, angled down towards the travel lanes of the roadway. These sensors use a beam of microwave energy to collect vehicle data, including speed, and volume, and sometimes occupancy depending on the manufacturer and signal type. See Figure 5-2 for an illustration of a radar detector and its detection area. The detector software then divides this area into user-definable "detection zones," where one zone corresponds to one lane.

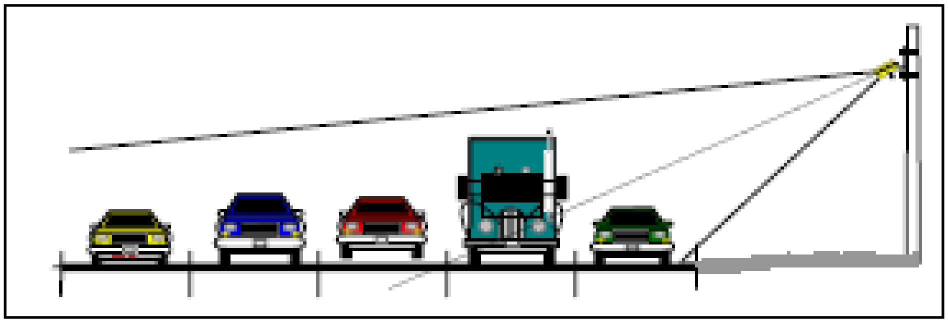


Figure 5-2: Side-Fire Radar Detector Orientation

When designing a microwave/radar detector location the designer must follow the steps below.

Determine:

1. Detector Location

   Detector location will vary based on their use – either data collection or incident detection.

   - If the detector is used for point data collection, the system needs may require a very specific detection area (e.g. a specific lane or entrance ramp, or a point on the main line). The designer should not place the detector outside of this detection area.
   - If the detectors are part of a corridor data collection system, they must be spaced approximately 0.5-1.5 miles apart.
   - If detectors are part of an incident detection system, they must be spaced at a maximum 0.5 miles apart.

2. Detector Quantity

   Radar detectors have a range of approximately 150' from the detector structure to the farthest detection point. At locations where the detection zone exceeds 150', multiple detectors must be used. This typically occurs at locations where two directions of travel must be captured. For example, an expressway with 3 12' lanes in each direction, 2 10' shoulders, and a 75' median is a total of 157'. This exceeds the detection capabilities of a detector, so one detector on either side of the roadway is necessary to capture all travel lanes.

3. Mounting Height and Setback

   Mounting Height – For a standard detection range of approximately 150', the sensor should be mounted approximately 25' above the roadway. Note that if the detector structure is located on an embankment or hill, the mounting height may be more or less than 25' from the base of the structure, depending on the structure elevation.

Setback – Detector setback is the distance from the edge of the nearest travel lane in the detection area to the detector itself. This setback is required so that the detector's radar beam can expand to cover the detection area. Newer radar detectors do not require a setback. However, a 20' setback from the edge of the closest detection lane is recommended.

The following is an example of the setback and height requirements as a function of lanes. This will vary, depending on the actual equipment used, so manufacturer's recommendations must always be considered during the site design.

# of 12-ft. lanes including median	Minimum Set-back (Feet)	Recommended Height (Feet)
1-3	10-13	17
4	15	17
6	20	17
8	25	20
8 + Median	> 30	> 23

Figure 5-3: Microwave/Radar Detector Recommended Height and Setback

4. Structure Type

Microwave detectors can be either free-standing on a 35' steel pole (as seen in Figure 5-2), or collocated with many existing structures such as:

- Type A Sign Structures
- Overhead Truss Structures
- Bridge Structures
- CCTV Poles
- Dynamic Message Signs

Microwave detectors are amenable to mounting configurations that vary from those listed above, including being mounted overhead of a lane on traffic signal mast arms, if the situation warrants this kind of deployment. This could include curve warning system detectors or other varying ITS systems. In mast arm configuration, follow the design guidelines for ETC tag reader mounted in this similar configuration found in Section 7.5.1.

The designer should collocate radar sensors on any of the above structures where the structures coincide with required detector spacing, and where the structure satisfies the mounting height and setback guidelines.

Mounting sensors on existing or new wooden poles is not acceptable.

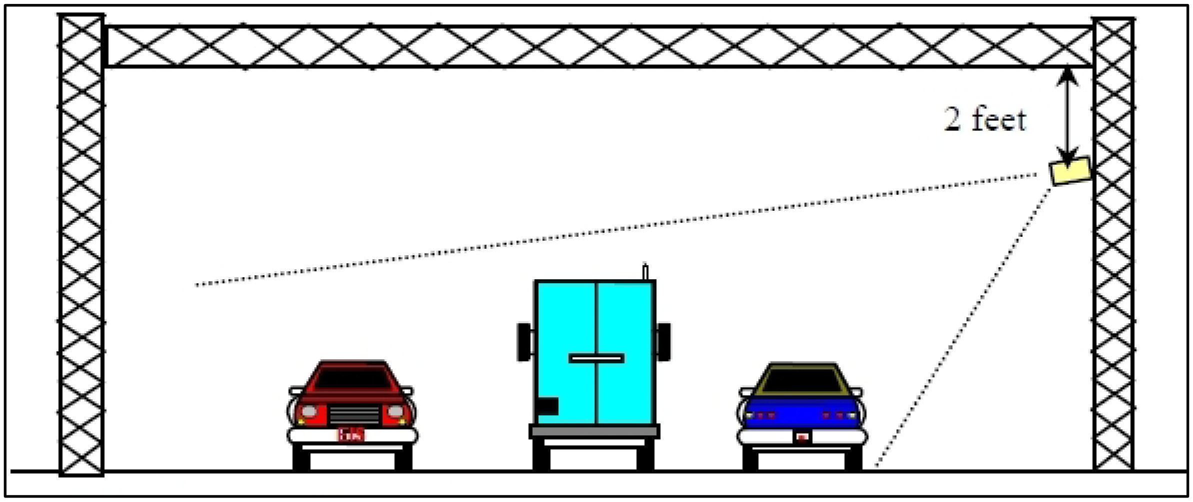


Figure 5-4: Microwave / Radar on Sign Structure

5. Obstructions

Microwave sensors can experience interference and disruption when obstructions such as guiderail, Jersey barriers, or high retaining walls are within the detection area. To minimize this interference, locations should be selected that minimize these obstructions. If obstructions are unavoidable, the designer should consider using multiple detectors to avoid the conflict. For example, if a roadway is separated by a jersey barrier median, one detector on either side of the roadway may be needed to capture all travel lanes.

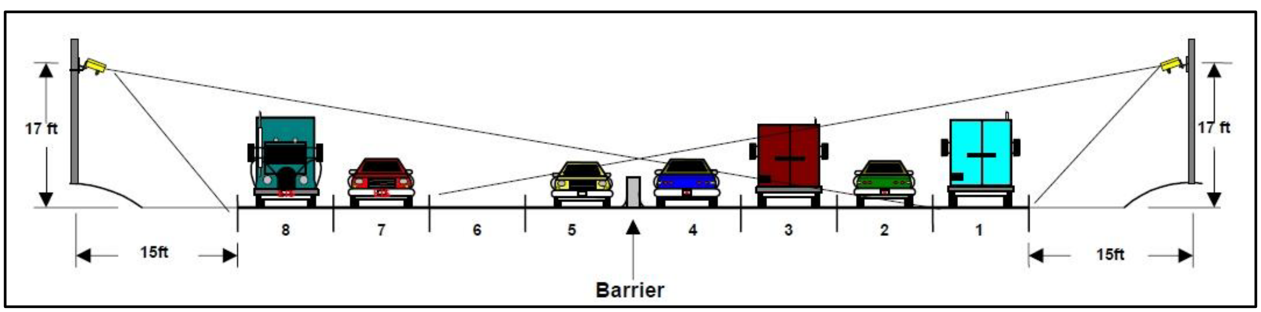


Figure 5-5: Side-Fire Detectors on Roadway with Barriers

5.6.2.1 Video Image Detection System (VIDS)

Video Image Detection systems consist of a video camera mounted above the roadway, angled down towards the travel lanes. The system is configured using proprietary software to collect data only from predetermined "zones" within the travel lanes. This video image is then run through software processing to detect vehicle presence, speed and volumes. Figure 5-6 displays an image from a VIDS camera, and the detection zones as defined in the system software.

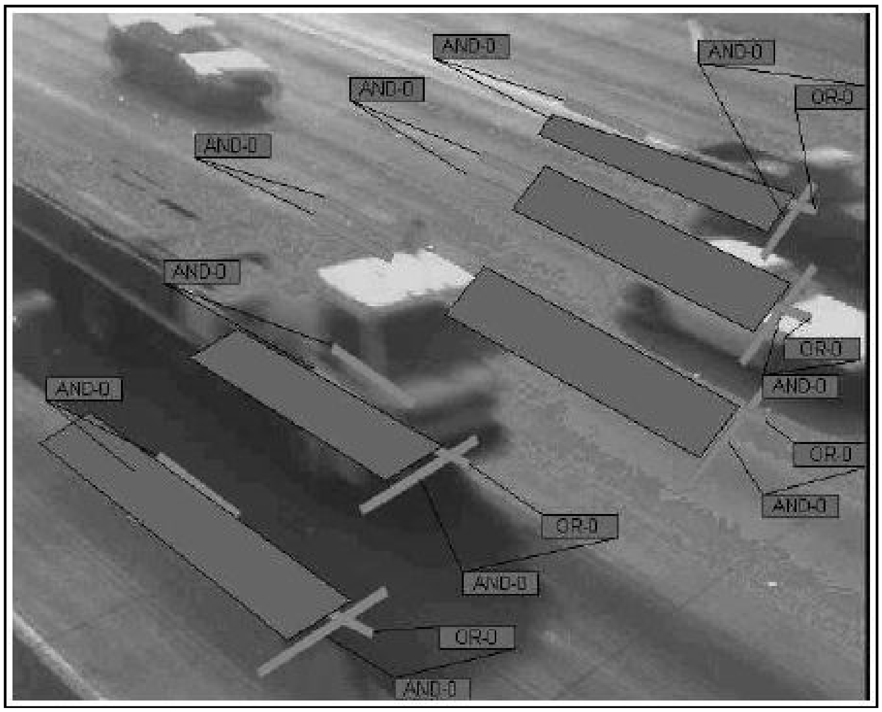


Figure 5-6: VIDS Camera Image and Detection Zones

When designing a VIDS system, the designer should follow the steps described below.

1. Detector Location
   Detector location areas are determined by system use – either data collection or incident detection.
   - If the detector is used for point data collection, the system needs may require a very specific detection area (e.g. a specific lane or entrance ramp, or a point on the main line). The designer should not place the detector outside of this detection area.
   - If the detectors are part of a corridor data collection system, they must be spaced approximately 1-1.5 miles apart.

- If detectors are part of an incident detection system, they must be spaced at 0.5 miles or less.

2. Detector Structure

Because VIDS detectors are above-roadway systems, it is highly recommended that they are collocated on existing structures such as:

- Bridges
- Truss Structures

If collocation is not possible because of spacing or other system needs, new overhead structures must be constructed. Traffic signal mast arms are the preferred structure for mounting VIDS cameras. If mast arms are utilized, they must meet the vertical clearance guidelines contained in this design guide and on the standard drawings. Typically, any above-lane structure must provide a minimum of 17'-6" clearance.

3. Detector Vertical Clearance and Quantity

VIDS can detect vehicles on as many lanes as are contained in the video image. At a height of 30', VIDS can detect up to three lanes simultaneously. At a height of 20', VIDS can detect up to 2 lanes simultaneously. At heights less than 20', only one lane can be detected per VIDS camera.

4. Configure Detection Zones (Post Construction)

VIDS systems detect vehicles on the roadway based on "detection zones" established within the detector software. Once installed, these zones must be defined for each travel lane that data is to be collected from. Each proprietor of VIDS technology utilizes a proprietary software system to define the detection zones.

Each detection zone must be defined such that only vehicles within the detected lane cross the zone. This will make certain that each detection zone gathers lane-specific data, and that vehicles are not counted more than once. See Figure 5-6 for an example of defined detection zones.

There are also Video Detection systems that utilize existing CCTV cameras, adding analytics to the "back-end" of the CCTV image. These systems require additional hardware (video servers) in which the analytics are added prior to being used by a TMC Operator. These systems have no adverse affect on the actual video, but can provide input into an existing ATMS in which, once an incident has been detected, it would generate an alarm through ATMS or simply route the image to the video wall, thus notifying the Operator of the incident. These systems are very comprehensive, where the analytics "re-learn" the image every time the CCTV camera is adjusted through PTZ. A significant drawback to these types of systems are that it requires a substantial amount of additional hardware for processing, typically adding an additional video server for every 8 CCTV cameras.

5.7 ITS Enclosure Placement

When the VDS system includes devices that will be designed, constructed, and maintained, as Department-owned assets, the enclosure and its associated components must be included in the design process.

Design criteria for a suitable ITS enclosure location includes the following:

- The enclosure for the VDS controller should always be pole-mounted on the VDS pole or existing structures in order to maximize cost savings.
- If possible, collocate the VDS cabinet components within another device enclosure.
- The enclosure should be oriented so that the maintainer is facing the roadway, while performing maintenance at the cabinet location.
- A concrete pad should be provided at the front of the enclosure for the maintenance worker to stand on while accessing the enclosure.
- Where possible, there should be adequate and safe parking conditions present for parking of a maintenance vehicle in the vicinity of the enclosure.
- See manufacturer's specifications to determine the maximum distance between the enclosure and the field device it services.

When it comes to designing the enclosure, there is no "standard" size. There is a wide variety of component manufacturers to choose from and this will usually impact the enclosure interior space requirements. In some case, co-located ITS devices may also share the same enclosure. This will further influence the design of the enclosure size.

Standard Specifications for an ITS enclosure can be found in Departmental publication 408 – ITS Device Special Provisions:

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Section 1201 – Intelligent Transportation Systems Device Enclosure

6 RAMP METERING SYSTEMS

6.1 System Purpose & Design Flow

Ramp metering systems are installed at expressway interchanges in order to improve traffic flow on the expressway main line. The goal of the ramp metering system is to prevent vehicles from "platooning" when entering the roadway. Platoons are groups of closely spaced moving vehicles. When platoons enter the expressway mainline, they cause traffic to slow or change travel lanes, which disrupts traffic flow and ultimately causes congestion. Meters utilize traffic signals to space out vehicles on the ramps before they merge with the main line. Meters separate vehicles by a matter of seconds, with typical spacing of approximately 2 seconds.

Ramp metering systems vary significantly in complexity. The simplest systems use a standard meter rate that operates regardless of traffic conditions. More complex, traffic-responsive systems consider traffic patterns in real-time, and adjust to meet the demands of the system. The complexity of the system depends on the type of interchange, interchange geometry, and the volume and intensity of traffic on the ramp and expressway mainline.

Ramp meters are utilized in highly-congested corridors or in urban areas. They are generally only installed at interchanges between limited access roadways and arterial, signalized roadways.

As part of the design of a ramp meter system, a comprehensive study must be completed. These systems cannot be installed without sufficient justification. The design study will:

- scrutinize the interchange or corridor in question to determine the need for ramp meters
- determine the net impact the meter will have on traffic flow on both the mainline and approach roadways
- identify many of the design parameters

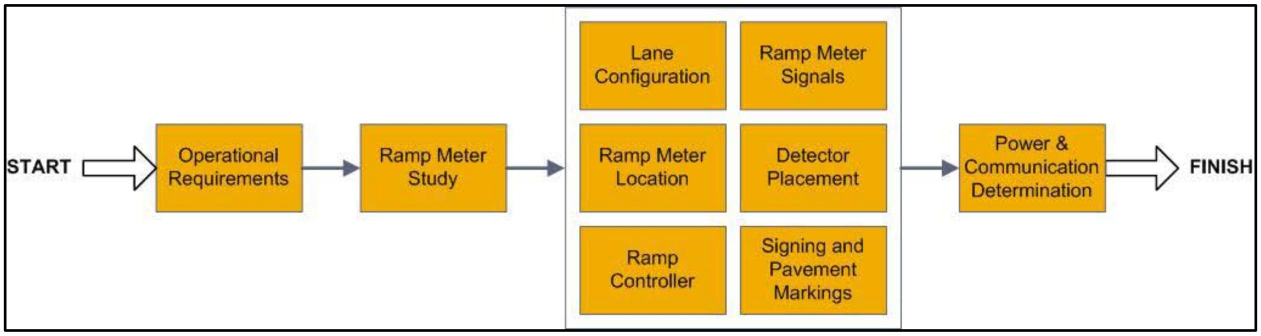


Figure 6-1: Ramp Meter Design Process

There are several Departmental and industry standards/requirements related to RMS. The table below highlights some of the more important ones:

Table 6-1: RMS Standards

Criteria	Relevant Standard
• Ramp Meter Systems	• Ramp Management and Control Handbook, FHWA, January 2006
• Signs and Signals	• Manual on Uniform Traffic Control Devices (MUTCD) Most current edition adopted by the Department. • American Association of State Highway and Transportation Officials (AASHTO) "Roadside Design Guide"
• Communication and Software	• National Transportation Communications for ITS Protocol (NTCIP 1203)
• Structure	• American Association of State Highway and Transportation Officials (AASHTO) • PennDOT ITS-1000M ITS standards • PennDOT ITS-1002M Structural standards
• Enclosure	• National Electrical Manufacturers Association (NEMA) TS 4 standards • PennDOT Pub 408, Section 1201 – ITS Device Enclosure

6.2 Design Considerations

The following list is intended to be a high level guide to assist ITS practitioners through the many criteria associated with a Ramp Metering System (RMS) design. Each section of the list corresponds to a section of this document chapter. The background, details, and specific regulations or guidance related to the design process for a RMS are contained in those referenced sections.

The criteria contained in this publication must be followed when designing new RMS. It is important to note/clarify however, that there will be instances where all of the criteria in these guidelines cannot be met.

Justification for deciding to go through with an installation, despite not being able to meet all criteria should be detailed by the designer. The goal of this process is to provide practitioners with guidance as well as providing the Department consistency with respect to RMS installations.

Table 6-2 contains an overview of the design considerations contained in this chapter and an outline of the chapter in general. For a design checklist that can be used for projects, see Appendix A, Section 10.5 **Ramp Meter Design Checklist**. The checkboxes in the right-hand column are a simple way to track whether or not the guidance in the left-hand column has been considered by the ITS practitioners during the design process.

Table 6-2: Ramp Meter Design Considerations

Pre-Design Planning	Section 6.1
• Is this deployment consistent with “needs” outlined in a Concept of Operations or Regional Operations Plan? • Is this deployment consistent with the ITS architecture?	
Ramp Meter Study	Section 6.3
• Has a comprehensive Ramp Meter Study been performed? • Do the results of the study support continuing with the deployment project?	
Lane Configuration	Section 6.5.1
• Do the number of lanes and the vehicles per green design support the projected ramp volume?	
Ramp Meter Location	Section 6.5.2
• Is the meter placed such that enough stacking space is available on the ramp to accommodate the queues it will generate? • If the ramp meter consists of more than one lane, does it provide a sufficient distance for the lanes to merge prior to the merge with the mainline?	
Ramp Meter Signals	Section 6.5.3
• Are the signals vertically spaced such that the driver can see the signal heads while parked at or just in front of the stop bar? • Are the signals designed in compliance with MUTCD Sections 4D and 4H? • Are the signals designed in compliance with FHWA requirements for Mast Arm Signal Poles, Signal Placement, and Signal Heads?	
Vehicle Detectors	Section 6.5.4
• Does the system design include all of the necessary detection areas; Demand, Ramp Queue, and Mainline? • Does the complexity/configuration of the system require the additional detection area; Passage, Exit Ramp, and Entrance Ramp?	

Signing and Pavement Markings	Section 6.5.5
• Do the signs and marking meet the MUTCD standards in Sections 2B.56, 2C.37, and 4I?	
Enclosure Placement	**Section 6.6**
• Is an enclosure required at this location? • Can personnel safely access the enclosure? • Is the enclosure located within 150 feet of the detectors? • Is it positioned such that maintenance personnel can access the enclosure while viewing ramp meter signal heads? • Is the enclosure mounted on an existing structure (where possible)? • Does the location and orientation provide adequate protection for the enclosure? • Has a concrete maintainer's pad been provided at the enclosure's main door?	
Power Requirements	**Section 8.1.1**
• Have the power requirements for the detector and all of the system components been determined?	
Power Availability	**Section 8.1.2**
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the detector site? • Have Step-Up/Step-Down requirement calculations been performed? • Have the metering options been determined?	
Power Conditioning	**Section 8.2**
• Have the UPS and power back-up requirements been determined and accounted for?	
Communications	**Section 9**
• Have the communication requirements for the detector been determined? • Has an appropriate communication source been located and confirmed within a reasonable proximity to the site? • If there are multiple communication options, have the pros/cons been studied? • Has the chosen communications option been reviewed by BIO? • If using public communications infrastructure, has service been coordinated with PennDOT BIO and the District?	
Environmental	
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	

6.3 Ramp Meter Study

In order to fully evaluate the impact that ramp meters have on a corridor, the designer must complete a comprehensive ramp metering study. This study will document the following:

- Need for the ramp metering system
- Anticipated benefits of the system
- Design parameters of the system

The results of the study will determine if the system should or should not be deployed. If the study recommends deployment, the designer should utilize the study and the guidance contained in this document as a basis for the design and operation of the system. While it won't answer all design or installation questions, it will serve as a foundation for the system, and provide the parameters for operating the system.

This chapter of the design guide will discuss many aspects of ramp metering systems, but will not provide the same level of guidance as the ramp metering study. The chapter will discuss alternatives of the design components, and existing practices, but will not provide project-specific design recommendations. Each project and site is different, and requires individual evaluation through the study and final design.

The specific design details that should be determined through the ramp meter study include:

- Lane Configuration/Number of Lanes
- Signal Location on Ramp
- Signal Type
- Detector Quantity and Type
- Detector Configuration
- Metered Rate
- Number of Vehicles per Green
- Advanced Traveler Warning Signage and Systems

6.4 Ramp Meter System Components

A ramp metering system consists of various components. Often these components are elements within larger freeway management architectures. These components are:

- **Ramp Metering Signal (Section 6.5.4) and Controller (Section 6.5.3) -** The signal is typically located to the drivers left, or on both sides of the ramp. Each ramp meter typically has one nearby weatherproof control cabinet which houses the controller, modem(s), and inputs for each loop.

- **Advance Warning Signage (Section 6.5.6) -** MUTCD (Manual of Uniform Traffic Control Devices) recommends one or two advance warning signs with flashing beacons indicating that ramp metering is active.
- **Check-In Detector (Section 6.5.5) -** The check-in, or demand detector is located upstream of the ramp metering cordon line. The check-in detector notifies the controller that a vehicle is approaching and to activate the green interval.
- **Check-Out Detector (Section 6.5.5) -** The check-out, or passage detector is located downstream of the ramp metering cordon line. The check-out detector notifies the controller that a vehicle has passed through the ramp meter and that the signal should be returned to red.
- **Merge Detector (Section 6.5.5) -** The merge detector is an optional component which senses the presence of vehicles in the primary merging area of the ramp.
- **Queue Detector (Section 6.5.5) -** The queue detector is located on the ramp, upstream of the check-in detector. The queue detector prevents spillover onto the surface street network.
- **Mainline Detectors (Section 6.5.5) -** Mainline detectors are located on the freeway upstream, and downstream of the on-ramp.

Ramps themselves must possess characteristics suitable for metering; namely the availability of vehicle storage space on the ramp and adequate acceleration and merge distance downstream of the meter cordon line.

Storage requirements to prevent queues from backing up onto the arterial network can be estimated from the projected metering rate and ramp demand.

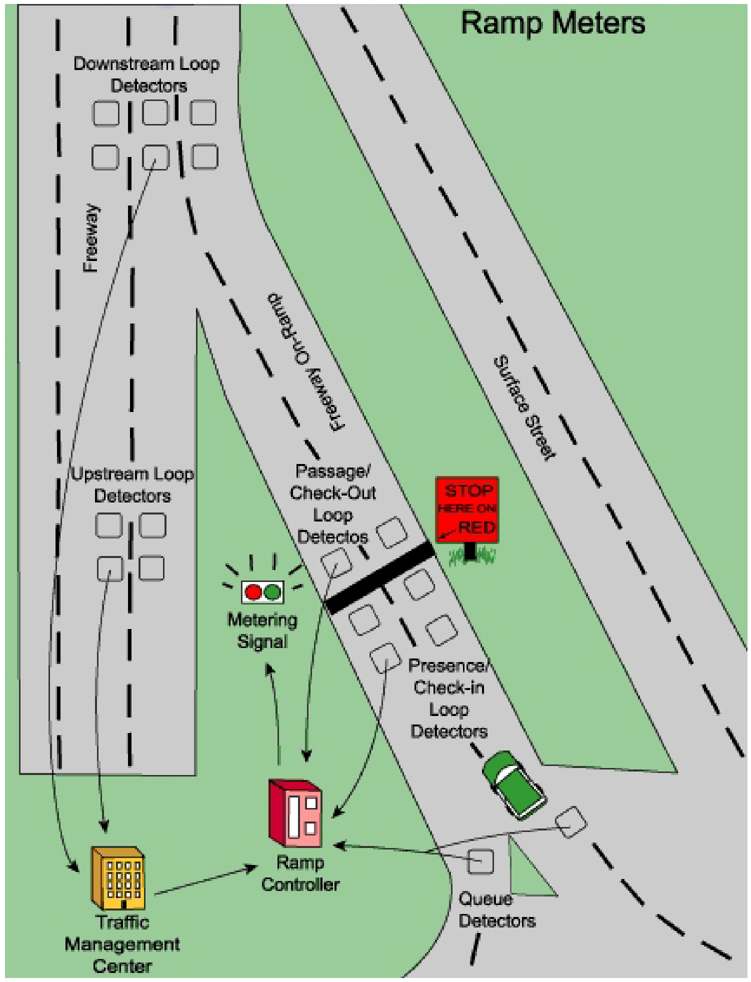


Figure 6-2: Typical Ramp Meter System Layout

6.5 Ramp Meter Design Considerations

6.5.1 Lane Configuration

Ramp metered entrance ramps can be comprised of single or multiple lanes. To determine the number of metered lanes, the designer must take two factors into account: vehicle volumes and the number of vehicles per green period.

The number of lanes must be determined in the ramp metering study. However, the Ramp Management and Control Handbook published by the FHWA provides guidelines to determine the number of lanes based on ramp volumes.

Resources

Ramp Management and Control Handbook, January 2006, U.S. Department of Transportation, Federal Highway Administration

The FHWA Ramp Management and Control Handbook also contains guidelines for the number of vehicles to allow per green period. The following chart indicates when it is appropriate to permit one or two vehicles per green:

Table 6-3: Ramp Meter Lane Determination

Ramp Volumes	Number of Metered Lanes	Vehicles Per Green
<1000 veh/h	• One Lane	• Single
900 - 1200 veh/h	• One Lane	• Dual
1200 - 1600 veh/h	• Two Lanes	• Single
1600 – 1800 veh/hr	• Two Lanes	• Dual

The FHWA Ramp Management and Control Handbook recommends that ramp lanes have a width of at least 12', an inside shoulder width of 4' and an outside shoulder width of 8'.

These guidelines should be used as rules of thumb when determining the appropriate number of ramp metered lanes. Other considerations such as project budget, environmental disturbance, existing structures, and other factors may influence the final design.

6.5.2 Location of Ramp Meter

The Location of the ramp meter and ramp meter signal "stop line," must be placed at a location on the entrance ramp that balances the need for upstream queuing/stacking area and downstream acceleration and merge area. The meter must be placed such that enough stacking space is available on the ramp to accommodate the queues it will generate.

The designer should utilize the methods of calculating queue storage requirements as described in the Ramp Management and Control Handbook - Chapter 9. As a rough estimation, queue lengths can be calculated by subtracting the metering rate from ramp volume over a specific period of time.

A commonly utilized rule of thumb is that the ramp should accommodate a queue of 10% of the peak hour volume. For example, if the peak hour volume is 1000 veh/h, the approximate stacking area should accommodate 100 vehicles.

Special consideration should be given to multi-lane ramp meter locations. Ramp meters consisting of more than one lane must provide a sufficient distance for the ramp lanes to merge prior to its merge with the mainline. This may increase the distance required from the meter to the mainline/ramp merge point to accommodate acceptable acceleration distance.

The exact location of the ramp meter on the entrance ramp will come from the ramp meter study. The rules of thumb included here are to be used to determine general placement areas, but will not address the needs of each unique situation.

6.5.3 Ramp Meter Signals

Single lane ramps should utilize a signal pole (vertical pole) with two mounted signal heads, placed on the left side of the stop line. The signals should be vertically spaced such that the driver can see the signal heads while parked at or just in front of the stop bar. A duplicate pole on the right side of the ramp can supplement the left side signal if deemed necessary.

Figure 6-3: Ramp Meter Signals

Two lane ramps should utilize two signal poles, one on either side of the ramp. For multi-lane ramps using staggered or multi-vehicle green periods, FHWA recommends that two signal heads be used per lane.

The Manual on Uniform Traffic Control Devices (MUTCD), 2009 edition, provides standards for all traffic signal applications. Ramp meter designers must follow the standards in Sections 4D and 4H of the MUTCD.

Resources

Ramp Management and Control Handbook (Section 4D.33), January 2006, U.S. Department of Transportation, Federal Highway Administration

The following items should be considered when placing signal supports:

- Signal supports should be placed as far as practical from the edge of the traveled way without adversely affecting the visibility of the signal indications
- Where supports cannot be located based on the recommended AASHTO clearances, consideration should be given to the use of appropriate safety devices

Resources

Roadside Design Guide (see Section 1A.11), American Association of State Highway and Transportation Officials (AASHTO)

6.5.4 Vehicle Detectors

Ramp metering systems require a series of vehicle detectors to provide input on various pieces of motorist information. While inductive loops have typically been used as the primary method of detection, other technologies can be used for detection as well, provided they produce all the input information required by the ramp meter controller. Viable technologies for vehicle detection include inductive loops, microwave detection, and video image detection (VIDS). However, many controller algorithms are designed to incorporate and utilize loop or loop imitator (such as VIDS system) data. Extra calibration may be required if non-loop detectors are used in the ramp metering system. See Chapter 5 for more information regarding vehicle detection options and installation guidelines.

Ramp metering systems employ a series of detectors at key locations. Depending on the complexity of the system, some or all of the detector locations may be deployed. A ramp metering system may utilize some or all of the following types of detectors:

Table 6-4: Detector Types

Detector Purpose	Description
Demand Detector	Located at the stop-line. Detects the presence of vehicles at each ramp meter lane. Also referred to as a check-in detector.
Passage Detector	Located just across the stop-line. Detects when vehicles pass the ramp meter. Also referred to as a check-out detector.
Ramp Queue Detector	Located at the intersection of the ramp and the surface street. Detects when the queue is at or exceeding ramp capacity. Intermediate ramp queue detectors may also be utilized.
Mainline Detector	Located at one or more location on the expressway/freeway mainline. Detects capacity of mainline, existing congestion, and speeds of each travel lane. Data can be used for data collection, and/or fed into the controller algorithm for traffic-responsive ramp metering systems.

Exit Detector	Located on exit-ramp at the metered interchange. Provides volume information to be used for system-wide, traffic-responsive ramp meter operations.
Entrance Detector	Located on **non-metered** entrance-ramps. Detects volumes entering the mainline of a ramp metered roadway. Volume information is entered into a corridor-wide traffic-responsive ramp metering system.

6.5.4.1 Demand Detection Area

The demand detector detects the presence of vehicles at the ramp meter stop-line. These detectors are essential for ramp meter operation because they tell the system when to activate.

The detection area for the demand detector should be approximately 45 feet, or the length of approximately 2 vehicles. The demand detection area must cover all metered lanes. Figure 6-4 displays a typical inductive loop passage detector/demand detector configuration.

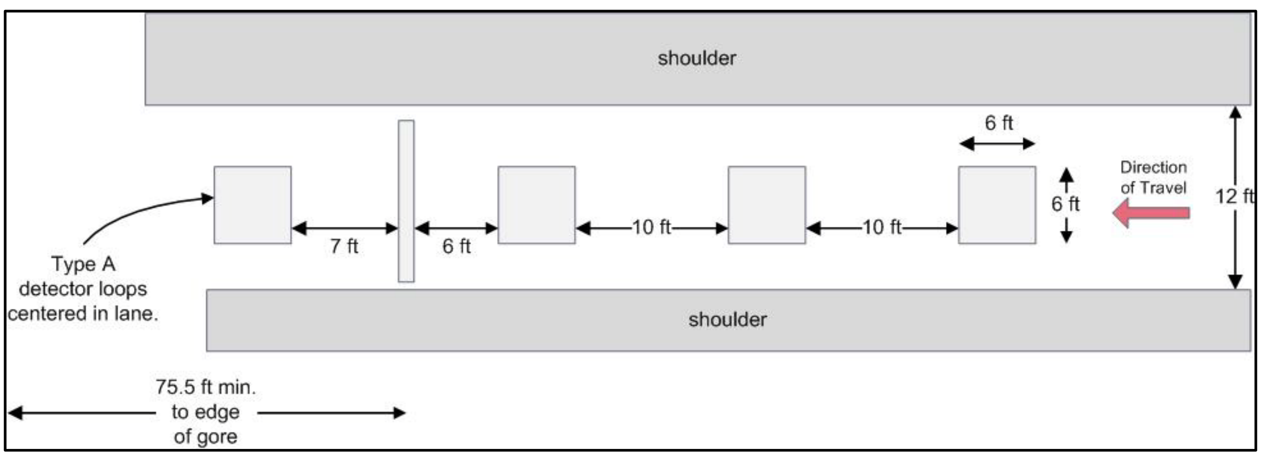


Figure 6-4: Typical Demand and Passage Loop Detector Configuration

6.5.4.2 Passage Detection Area

Passage detection area is used to detect vehicles passing through the ramp meter system. This provides the system with vehicle volumes entering the roadway, and provides confirmation that the vehicles are obeying the ramp meter signals. Depending on the type of system, this detection area may or may not be essential to ramp meter operations. Figure 6-5 displays a typical inductive loop passage detector/demand detector configuration.

6.5.4.3 Ramp Queue Detection Area

Ramp queue detection area is essential to a traffic-responsive ramp metering system. The detector is located at the top of the ramp, near the intersection with the surface street. It senses when a ramp is at capacity, and if the queue is in danger of reaching or backing up onto the surface street. Additional detection zones may be set up at midway points on the ramp in order to detect general queue size.

Queue detection is a crucial input for a traffic-responsive system algorithm, and must be included in the ramp meter system.

6.5.4.4 Mainline Detection Area

Mainline detection areas are located on the expressway/freeway thru lanes just upstream of the ramp gore area. The zone must include all thru lanes. This detection zone provides essential mainline traffic operation data such as speed and volume. These data are inputs to the ramp meter algorithm that are necessary to determine the available capacity of the main line. Available capacity in turn determines the meter rate.

Figure 6-5 displays typical inductive loop mainline detector configuration. If using loops, multiple loops must be installed in sequence in order to accurately detect speeds and vehicle queues.

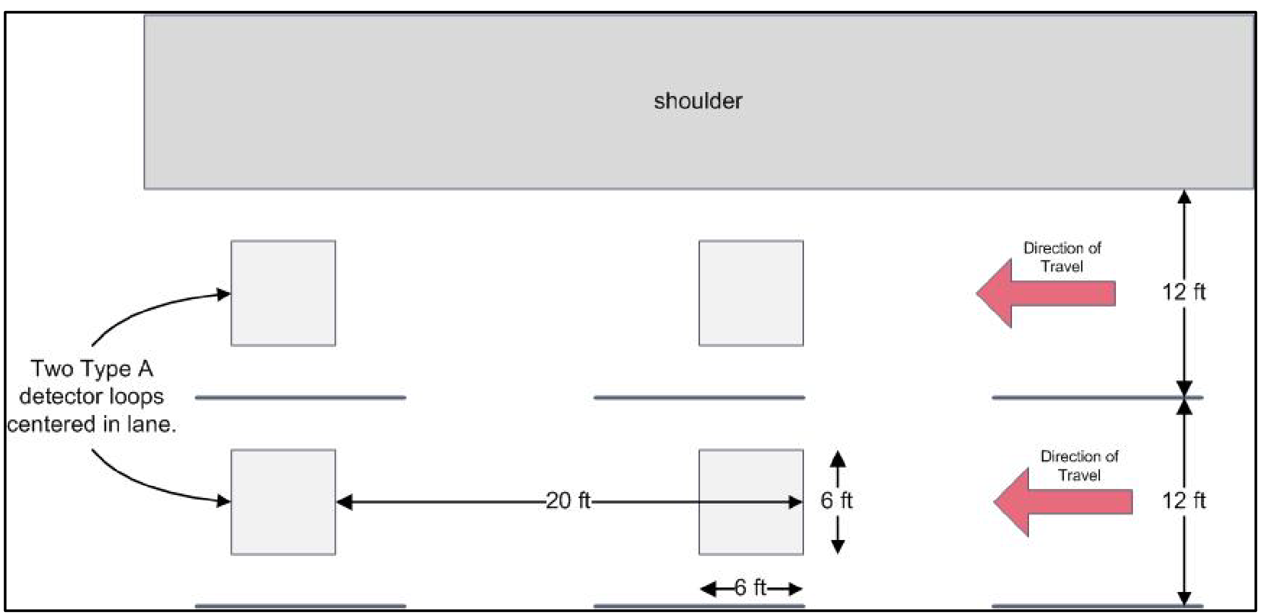


Figure 6-5: Typical Mainline Inductive Loop Detector Layout

6.5.4.5 Exit Ramp Detection Area

Exit ramp detection area is located at some point on the exit ramp of an interchange equipped with a ramp metering system. The intent of this detection area is to collect vehicle volume data, which is used in many ramp metering system algorithms. While exit ramp detection is desirable, it may not be a requirement for a functional, traffic-responsive ramp metering system. The need for exit ramp detection will be determined by the ramp metering algorithm selected for the project.

6.5.4.6 Entrance Ramp Detection Areas

Entrance ramp detection areas can be located on ramps that are NOT metered, but are within a ramp metered corridor or system. These detection areas are intended to collect volume data from vehicles entering the mainline, which decrease its available capacity. While these volumes are not required, they are inputs to many ramp meter algorithms.

6.5.4.7 Ramp Meter Signing and Pavement Markings

Ramp meter technology is currently not a typical traffic management method utilized in the Commonwealth. Drivers are generally not yet accustomed to ramp meters, so any installation may cause confusion and dangerous conditions if not properly announced to motorists. If motorists do not know to expect ramp meters, they may swerve, make other erratic motions, or brake abruptly causing hazardous conditions to themselves and drivers around them.

Abundant, well placed, clear signage and pavement markings are critical to effective and safe ramp meter installations. The need for signage increases with the complexity of the system. For example, ramp meters at high-volume or freeway-to-expressway interchanges require a network of signage that includes overhead signs equipped with flashing beacons.

<u>Standard Ramp Meter Signs</u>

Ramp Management and Control Manual signs must adhere to Pub 236 as well as MUTCD standards (see Section 2B.56, 2C.37, and 4I for specifics on Ramp Metering signs). Any of these signs may be equipped with flashing beacons that activate upon ramp meter operation to increase the visibility of the sign. The use of flashing beacons should be determined on a project by project basis, and must be approved by the Department.

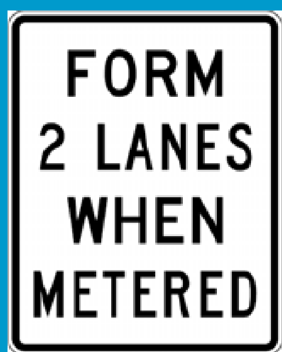
Sign	Location	Application
	Placed on the arterial approximately 61 meters (200 feet) upstream of the ramp entrance point. The sign should generally be placed on the right side of the arterial.	This warning sign is accompanied by a yellow flashing beacon that is activated during metered periods to alert motorists of the upcoming controlled ramp.
	Positioned near the beginning of the dual-lane queue storage reservoir on the right side of the on-ramp (or positioned on both sides of the ramp).	This regulatory sign is used to convert the single lane on-ramp into a dual-lane queue storage reservoir during ramp meter operations.
	Placed on both sides of the on-ramp at the signal stop bar. This sign is placed on the signal pole under the post-mounted configuration.	This regulatory sign identifies the signal stop bar location and is used to align drivers over the demand detectors placed upstream of the stop bar.

Figure 6-6: FHWA Ramp Management and Control Manual Ramp Meter Signage Location and Application (Table 1)

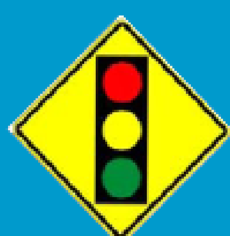
Sign	Location	Application
	Can be optionally placed either on the signal pole or with the "Stop Here on Red" regulatory sign under a mast arm configuration. There are also signs that state "Two vehicles per green" for dual release.	This regulatory sign is used to inform motorists of the intended traffic control method under ramp metering operations.
	Can be placed on the signal pole.	This regulatory sign is used when converting a non-metered HOV by-pass lane to a metered operation. Also may be used on new installations where potential for confusion exists.
	Placed upstream of the ramp meter and 120 to 180 meters downstream of the "Meter On" sign.	This advance warning sign informs the motorist that the ramp meter is turned on.
	Placed upstream of the ramp meter.	This warning sign is used to inform motorists that a traffic signal is ahead and to be prepared for the potential to stop.
	Placed approximately 30.5 meters (100 feet) downstream of the stop bar on the right side of the ramp when there are two ramp lanes that merge prior to entering the freeway.	This warning sign is used to inform motorists of the need to merge with another ramp lane prior to entering the freeway mainline.

Figure 6-7: FHWA Ramp Management and Control Manual Ramp Meter Signage Location and Application (Table 2)

Pavement Markings

Ramp metering systems should utilize pavement markings consistent with standard signalized intersections and freeway ramp operations, including: stop lines, merge lines, and dashed lane separator lines. Lines may be paint, plastic, or raised pavement markers. All pavement markers should conform to the guidelines set in Pub 111M as well as Chapter 3B (Pavement and Curb Markings) of the most recent version of the MUTCD manual adopted by the Department.

6.6 ITS Enclosure Placement

See manufacturer's specifications to determine the maximum distance between the control cabinet and the field device it services.

The ramp controller system consists of a cabinet, controller, load switches, input files, loop amplifiers, and other miscellaneous devices, very similar to traffic signal systems. The controller must be capable of meeting the needs and functions outlined in the ramp metering study. Many standard over the counter controllers are available that meet the general needs of a ramp metering system. The most common controllers are "type 170s" or "type 2070s." The Model 170 controllers are becoming more and more obsolete, so new installations should utilize the Advanced Transportation Controller (ATC) 2070, except in cases where it will conflict with existing systems and/or system software.

All ramp controller equipment should be housed in a standard NEMA cabinet. The cabinet must be positioned at the ramp meter location and must satisfy the following requirements:

- Easily Accessible for Maintenance – access to the controller should not require special vehicles or equipment.
- Positioned such that maintenance personnel can access the cabinet while viewing ramp meter signal heads.
- Does not obstruct vehicle sight distance of the ramp or the ramp meter signal head
- Protected from errant vehicles – either located outside of "clear zone" or behind a barrier such as guide rail.
- Facilitate a connection to the TMC or remote location that controls and monitors the ramp meter.
- A concrete pad should be provided at the front of the cabinet for the maintenance worker to stand on while accessing the cabinet.

7 TRAVEL TIME SYSTEMS

7.1 System Purpose & Design Flow

The primary function of travel time systems is to provide en-route motorists with an estimated travel time to a destination(s). These travel times may be displayed to the public in a variety of ways, including; Dynamic Message Sign (DMS) display, websites, kiosk, and dedicated travel time signs (DMS display is the primary means of travel time display). Travel time systems are an excellent way to add value to the ITS network by utilizing existing DMS more frequently, and are typically installed in areas with existing DMS, or as part of a project that includes DMS installation. Travel time systems should be considered along freeways in urban areas, key commuter routes, and areas of frequent recurring congestion. The type of information distributed to the public varies greatly depending on the ownership of the data/equipment, detection method and reporting needs.

A typical travel time system may consist of the following elements:

- Travel time detectors
- Travel time detector equipment (in enclosure in field)
- Dynamic Message Signs
- Static Travel Time Signs with Dynamic parts
- DMS control equipment (in enclosure in field)
- Communications cable/conduit
- Electrical cable/conduit
- Travel time software/hardware in TMC
- DMS software/hardware in TMC
- Control workstation in TMC
- Travel time calculation algorithm

Figure 7-1: Travel Time Display on a DMS

As travel time systems utilize DMS for display, the location(s), and capabilities of existing DMS must be considered during design. If the travel time detectors are being installed along with new DMS, the same factors must be considered. In order to effectively design a travel time system, the reporting needs must consider where the travel times can be displayed, and how many travel times can be displayed at each DMS. If a DMS is only capable of displaying one travel time, then only one destination will be useful. If the DMS is capable of displaying multiple travel times, multiple destinations may be used. All DMS travel time display messages must comply with the PennDOT Dynamic Message Sign Operating Guidelines (2008).

DMS location(s) and capabilities must be considered during the design of a travel time system. All DMS travel time display messages must comply with the PennDOT Dynamic Message Sign Operating Guidelines.

To maximize the effectiveness and minimize the construction costs of a travel time system, the reporting needs, data ownership, detection method, and device placement must all be carefully considered when designing and deploying any new system. The design process can be simply illustrated in the following figure.

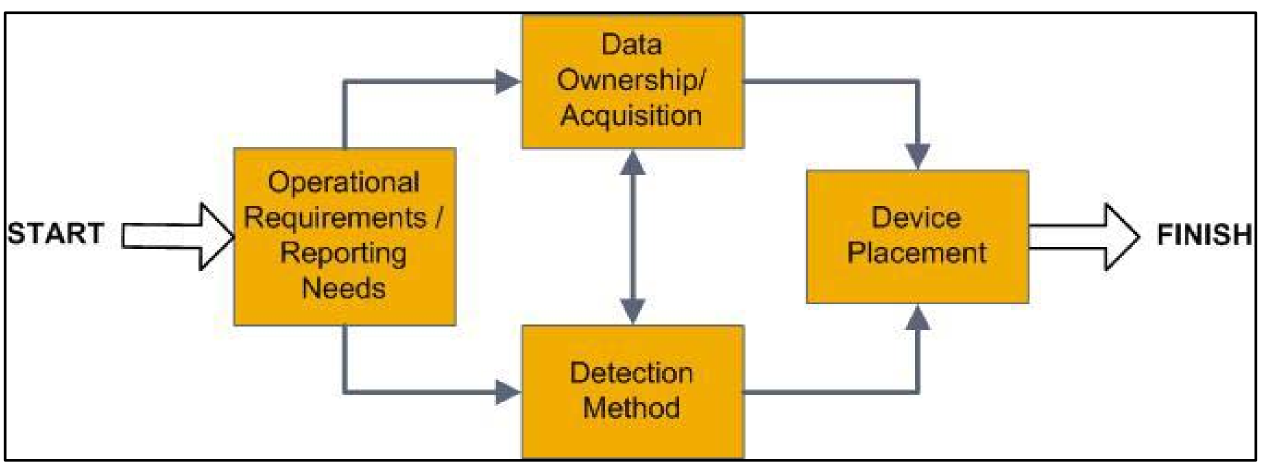


Figure 7-2: Travel Time Detector Design Flow Chart

- First, the operational requirements and system reporting needs must be considered. These needs will specify the route on which the system will be implemented, and the key routes/locations that will be identified by the travel time notifications.

- Second, the Department must determine if it wishes to install, operate, and maintain the data collection equipment and the travel time calculation algorithm, or if it wishes to acquire this data through private 3rd party providers. The determination of data ownership is the largest difference between approaches to acquiring travel time information.
- Third, once ownership has been determined; the detection method (e.g. technology choice) may be selected with consideration to the reporting needs.
- The final step in this design process is the placement of the detection device; this is often dictated by the reporting needs and the detection method.

7.2 Design Considerations

The following list is intended to be a high level guide to assist ITS practitioners through the many criteria associated with a Travel Time System (TTS) design. Each section of the list corresponds to a section of this document chapter. The background, details, and specific regulations or guidance related to the design process for a TTS are contained in those referenced sections.

The criteria contained in this publication must be followed when designing new TTS. It is important to note/clarify however, that there will be instances where all of the criteria in these guidelines cannot be met. Justification for deciding to go through with an installation, despite not being able to meet all criteria should be detailed by the designer. The goal of this process is to provide practitioners with guidance as well as providing the Department consistency with respect to TTS installations.

Table 7-1 contains an overview of the design considerations contained in this chapter and an outline of the chapter in general. For a design checklist that can be used for projects, see Appendix A, Section Section 10.6 **Travel Time System Design Checklist**. The checkboxes in the right-hand column are a simple way to track whether or not the guidance in the left-hand column has been considered by the ITS practitioners during the design process.

Table 7-1: Travel Time Design Considerations

Pre-Design Planning	Section 7.1
• Is this deployment consistent with "needs" outlined in a Concept of Operations or Regional Operations Plan? • Is this deployment consistent with the ITS architecture? • Have DMS display capabilities been considered in selecting the reporting needs?	
Data Ownership/Acquisition	**Section 7.3**
• Have departmental capabilities, reporting needs, funding, data quality, and existing infrastructure been considered in deciding data ownership/acquisition?	
Detection Method	**Section 7.4**
• If an RTVD system has been selected; has a penetration study been completed? • Has RTVD or point vehicle detection been selected? o If not, has a plan for data capture and verification been created? • Has a cost effective detection method been selected?	
Detector Placement	**Section 7.5**
• Have the reporting needs been used in selecting the locations to be monitored? • Have the DMS display capabilities been used to determine the number of travel time destinations? • Do the selected locations conform to spacing requirements? • Are existing structures, power, and communications being used wherever possible? • Are all field devices protected by guiderail and/or located outside of roadway clear zone? • Are devices located in such a way that they are accessible to maintenance staff?	
Enclosure	**Section 7.6**
• Is an enclosure required at this location? • Can personnel safely access the enclosure? • Is the enclosure located within 150 feet of the detector? • Is the enclosure mounted on an existing structure (where possible)? • Does the location and orientation provide adequate protection for the enclosure? • Has a concrete maintainer's pad been provided at the enclosure's main door?	
Power Requirements	**Section 8.1.1**
• Have the power requirements for the detector and all of the system components been determined?	

Power Availability	Section 8.1.2
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the detector site? • Have Step-Up/Step-Down requirement calculations been performed? • Have the metering options been determined?	
Power Conditioning	**Section 8.2**
• Have the UPS and power back-up options been determined and accounted for?	
Communication	**Section 9**
• Have the communication requirements for the detector been determined? • Has an appropriate communication source been located and confirmed within a reasonable proximity to the site? • If there are multiple communication options, have the pros/cons been studied? • If using public communications infrastructure, has service been coordinated with PennDOT BIO and the District?	
Environmental	
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	

7.3 Data Ownership / Acquisition

A key decision in the design of a travel time system involves the acquisition and ownership of travel time data. Private service providers can offer flexibility to the Department. The Department must decide between outsourcing its travel time data and collecting the data on its own. This decision must be based on a number of factors including; Department capabilities, reporting needs, data quality, funding, and existing infrastructure (e.g. overhead structures, communications, electrical service, etc.). Table 7-2 provides considerations for each of the factors mentioned above.

While considering these factors, the Department must decide who will own, operate, and maintain the travel time data acquisition system. If the Department chooses to outsource this, a private service provider must be selected based on the reporting needs defined in the Operational Requirements. If the Department chooses to design and install a Department-owned travel time data acquisition system, a proper detection method must be selected. (refer to Section 7.3 and also Chapter 5 for more information on detection options)

Table 7-2: Data Ownership Considerations

Consideration	PennDOT Owned	Service Provider
• Department Capabilities	• In house staff or consultant required to operate travel time system • IT staffing or consultant needed to maintain travel time calculation algorithms	• Can minimize the staff required to operate system
• Reporting Needs	• New, travel time detectors are more easily installed along roadways with existing structures, communications and electrical service.	• A large and diverse travel time network may be more easily facilitated by a private service provider • PennDOT may not own the data acquired by a private service provider
• Funding	• Department-owned devices may represent a significant initial cost	• May represent a low initial cost, followed by a recurring service fee
• Data Quality	• High data quality can be achieved where desired	• Data quality dependent on outside factors (ridership, sensor locations)
• Existing Infrastructure	• Significant infrastructure may be required	• Private service providers require little/no additional infrastructure

Department ownership and operation of travel time data, and in-house travel time calculations are most suited to situations such as:

- Districts with in-house IT staff and resources capable of maintaining the devices and software.
- Areas with extensive existing infrastructure, where the need for new infrastructure will be minimized.
- Districts that prefer to avoid outsourcing and prefer the use of internal staff.

Department outsourcing or contracting of services to provide travel time data is most suited to situations such as:

- Areas where an expansive network of fixed traffic sensors does not exist.
- Regions where a combination of freeway and arterial travel times is desired.
- Districts where the reporting needs extend beyond the urban area into the suburban and/or rural area.

7.4 Detection Method

The detection method is determined through careful consideration of the reporting needs, system ownership, cost, and existing infrastructure. The most prominent technologies are summarized in the table below

Table 7-3: Detection Methods

Detection Method	Method	Components	Example
RFID Transponder based Vehicle Detection (RTVD)	Direct origin-to-destination detection of travel time using RFID tag	• Lane kit (1 per 2 lanes) • Tag Reader (in cabinet) • TRANSMIT Software housed in TMC*	E-Z Pass Readers-PennDOT District 6-0
Point Vehicle Detection	Fixed detection of traffic volume and capacity	• Pole mounted detectors spaced at a fixed interval • NO cabinet in field • Software –NOT PROCURED STATEWIDE-Will be part of NextGEN ATMS	Traffic.com, RTMS, Wavetronix
Bluetooth Technology	Cell phone/ GPS/Bluetooth devices as probes	• Base unit • Cellular modem • Mounting pole	TraffiCast/Blue Toad-Currently deployed as pilot in PennDOT District 6-0
Probe Data service provider	Fleet GPS data collected to determine travel times	• None-Data feed is provided and is then incorporated into control software	INRIX

*PennDOT owns a user's license for the TRANSMIT software.

RTVD systems and Point Vehicle Detection are preferred options, and are allowed on any ITS project. Other options may only be utilized on pilot projects (until data accuracy is verified). Pilot projects must contain plan for data capture and verification.

Due to the RTVD system's reliance on RFID tag usage, it may be necessary to first complete a Penetration Study along the selected route. The purpose of the Penetration Study is to determine if there is sufficient tag usage along the targeted route; ensuring that there will be enough data to provide accurate travel times. A penetration rate exceeding 4% is required (Sanwal and Walrand, 1995); however it is recommended that the penetration rate be 10% or greater. Due to the proliferation of RFID tags throughout the state, this should be easily satisfied. Each detection method presents various advantages and disadvantages, some of which are presented in the table below:

Table 7-4: Detection Method Advantages and Disadvantages

Detection Method	Advantages	Disadvantages	Ideal Situation
RFID Transponder based Vehicle Detection (RTVD)	• Accurate, proven technology • Currently implemented	• Limited to overhead installations • Only 2 lanes of coverage per detector	Freeways with existing infrastructure (e.g. overhead structures, communications, electrical service, etc.)
Point Vehicle Detection	• Low cost when co-located with other devices • Proven technology	• Multiple detectors required • Requires advanced software algorithm for travel time calculation	Small monitoring area with existing infrastructure
Bluetooth Technology	• Large area can be monitored with one installation • Low cost	• Only deployed as pilot in Pennsylvania • Data accuracy not guaranteed and needs verification • Un-proven technology	Multi-lane freeways (due to large monitoring range) and all typical roadways
Probe Data service provider	• No infrastructure required • Large coverage area	• Data sharing issues • Dependence on third party data	Areas without existing infrastructure. Where arterial travel times are desired. Rural areas

Costs vary significantly between detection methods, and are affected by the amount of new infrastructure required.

- Point vehicle detection is often a cost effective solution in urban areas with existing structures and communications; if the detectors cannot utilize existing facilities, they can become quite costly.
- Bluetooth travel time detectors can be significantly less expensive than other detection methods due to the limited number of required field devices, wireless communications, and simple mounting technique, but are only considered for pilot projects.
- Probe data service providers offer a variety of pricing options, but are currently only considered for pilot projects.

RFID Transponder based Vehicle detectors are the preferred cost-effective solution for most new ITS installations due to the low number of required installations (when compared to point vehicle detectors).

7.5 Detector Placement

Once the detection method has been selected, it is possible to begin the device placement phase of design. Device placement is most heavily dependent on the reporting needs and detection method. The reporting needs will specify the key destinations that will be part of the travel time system.

Table 7-5: Detector Placement

Detection Method	Detector Placement
Origin-to-Destination (Figure 7-3)	• At the message display point (e.g. DMS) • Number of destinations should not exceed DMS display capabilities • At key destinations (e.g. major interchanges)
Point Vehicle Detection	• Detectors placed at a fixed interval (maximum spacing of ½ mile) along the roadway segment
Probe Data Service Provider	• No field devices required

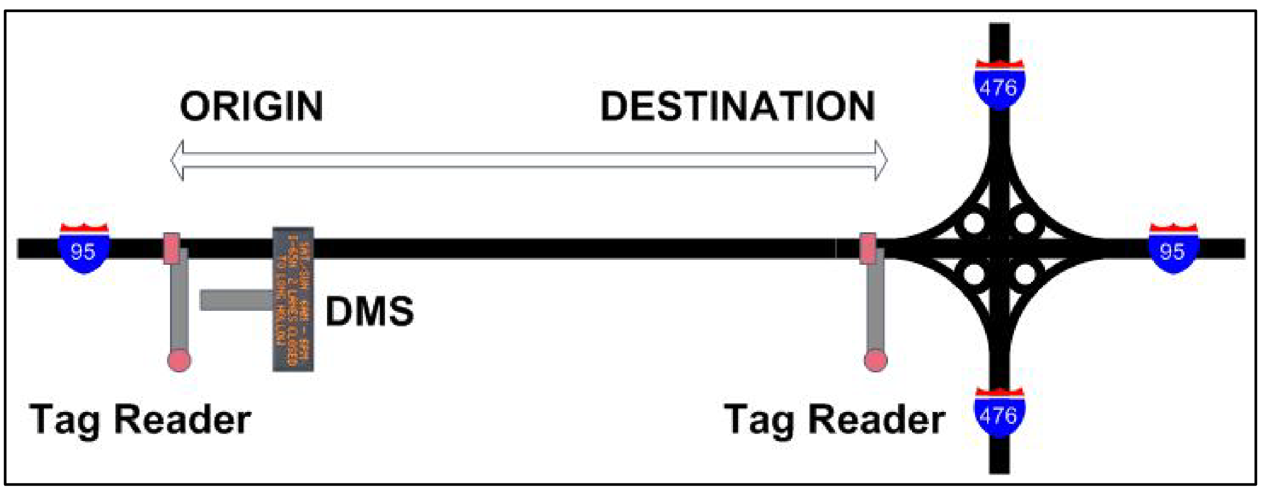


Figure 7-3: Origin-Destination Travel Time Layout

Ideally, travel time field devices are located on existing structures, and utilize existing communications and power connections. If this is not possible, the considerations outlined in the table below should be referred to when selecting the site and placement of the field device.

Table 7-6: Site Selection Considerations

Travel Time Field Device Site Selection and Placement Considerations	
Utility Availability	• Consider proximity to power and communications • If fiber optic communication is used, try to place the device on the same side of the roadway to eliminate lateral crossings
Safety and Device Longevity	• Ideally, locate devices outside of roadway clear zone (see PennDOT DM-2, Section 12.1) • Protect mounting structure with guiderail inside of clear zone, but consider lateral deflection and maintenance vehicle access • Medians are not the preferred location, but wide medians may be considered if suitable roadside locations are not available • To reduce site erosion, reduce construction costs, and provide longer device structure life, avoid locating the mounting structure on sections that have a fill slope of greater than one vertical to three horizontal
Operational Considerations	• Install in urban areas, along key commuter routes, and other areas of frequent recurring congestion
Maintenance Considerations	• The device should be located such that a maintenance vehicle can park in the immediate vicinity, without necessitating a lane closure or blocking traffic • A concrete maintainer pad must be provided; facing the cabinet (where applicable)
DMS Display Capabilities	• If the DMS is only capable of displaying one destination, only one destination detector is necessary. If the DMS can display multiple destinations (2-3), more detectors may be deployed.

7.5.1 RFID Transponder based Vehicle Detectors (RTVD)

RFID Transponder based Vehicle Detectors involve an overhead lane kit and an RFID tag reader that is located in a roadside cabinet. One lane kit, when mounted directly over the roadway (over the center line), is capable of monitoring two lanes. The lane kit mounting techniques, in order or preference are:

1. On an existing overhead sign structure
2. On an overhead bridge (with coordination from the PennDOT District Bridge Unit)
3. Mounted on a new traffic signal mast arm of sufficient length to place the lane kit directly over the center line

All installations must maintain a minimum vertical clearance of 17'-6" (maximum height of ~18', consult manufacturer for specifications).

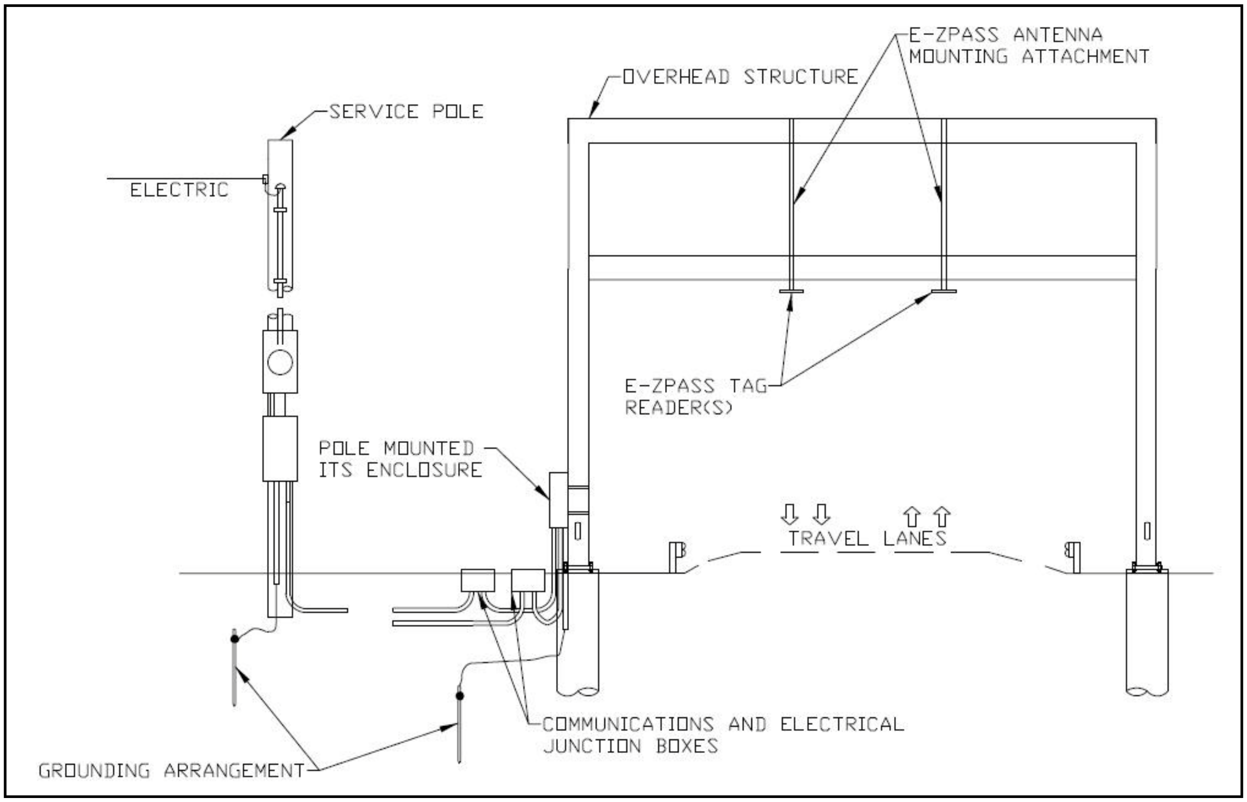


Figure 7-4: RFID Transponder based Vehicle Detector installation on existing structure

An RTVD installation requires a cabinet. Consider the following when selecting cabinet location and mounting:

- The cabinet must be installed in the vicinity of the lane kit (within 150 ft; for larger distances consult manufacturer).
- Mount on existing structures (where possible) in order to maximize cost savings.
    - These cabinets are of considerable size and pole mounting may not be possible.

- If no suitable poles/structures are available, the cabinet may be ground mounted at a more convenient location with easier access, such as adjacent to a frontage road.
    - o A concrete maintenance pad should be installed for accessing the cabinet

7.5.2 Point Vehicle Detection

Point vehicle detection systems consist of a series of roadside detectors (typically pole mounted) located at a fixed interval along the route (typically ½ mile). Point vehicle detectors can be somewhat hampered by typical roadway obstructions (e.g. sound walls, median guiderail, etc.), which frequently limit their ability to monitor all lanes in both directions of travel. However, when mounted correctly, and in an obstruction free environment, are often capable of monitoring a complete roadway.

Wherever possible, detectors should be located on existing structures, and should utilize existing power and communications connections. In order to provide accurate travel time data from one point to another, it is necessary to place point detectors along the entire segment (at ½ mile spacing). If device placement exceeds this allowed spacing, the quality of the data will be diminished, to the extent that it may not be fit for public dissemination.

Detectors should be located on existing structures, and should utilize existing power and communications connections.

Point vehicle detector installations often require a cabinet located in the general vicinity of the detector; however they are not required for all installations. Consider the following when selecting cabinet location and mounting:

- The cabinet must be installed in the vicinity of the detector (within 150 ft; for larger distances consult manufacturer).
- Cabinets should be mounted on existing structures (where possible) in order to maximize cost savings.
- If the existing structure is not suitable, the cabinet may be ground mounted at a more convenient location with easier access, such as adjacent to a frontage road.
    - o A concrete maintenance pad should be installed for accessing the cabinet.

7.5.3 Bluetooth Technologies

Bluetooth technologies involve a pole mounted wireless base unit with no other field equipment. One Bluetooth base unit has a sensing range of 175 ft. and is thus capable of monitoring many lanes in both directions; often covering full roadways. The large sensing range of a Bluetooth base unit allows flexible site placement. The device needs to be positioned along the side of the roadway at a height of six to ten feet. The device does not require an overhead structure, and can be mounted on a new pole, or on an existing structure.

7.5.4 Probe Data Service Providers

If a probe data service provider is selected as the travel time data provider, no device placement is required. Probe data service providers collect private data from a variety of GPS-enabled devices (cell phones, transponders, GPS navigation devices, etc.) and provide travel times in the following manner:

- The probe data service provider establishes a data sharing relationship with various companies (e.g. UPS, FedEx, etc.).
- The provider collects data from GPS enabled devices on fleet vehicles from these companies
- The service provider then utilizes this data from their fleet vehicles to generate average travel times.
- This data can then be provided directly to the Department via an XML feed (other formats are typically available).

7.6 ITS Enclosure Placement

When the travel time system includes devices that will be designed, constructed, and maintained, as Department-owned assets, the enclosure and its associated components must be included in the design process.

Design criteria for a suitable ITS enclosure location includes the following:

- When possible, the enclosure for the travel time controller should be pole-mounted on the detector pole or existing structures in order to maximize cost savings.
- In locations where the pole is difficult to access, the enclosure may be ground-mounted at a more convenient location with easier access, such as adjacent to a frontage road.
    - The enclosure is to be placed in the safest possible location, generally along the right shoulder.

  - A ground-mounted enclosure should be located at a minimum distance from the barrier, based on the design and type of barrier used. See standard drawings for appropriate minimums.
  - The enclosure should be oriented so that the maintainer is facing the roadway, while performing maintenance at the cabinet location.
- A concrete pad should be provided at the front of the enclosure for the maintenance worker to stand on while accessing the enclosure.
- Where possible, there should be adequate and safe parking conditions present for parking of a maintenance vehicle in the vicinity of the enclosure.
- See manufacturer's specifications to determine the maximum distance between the enclosure and the field device it services.

When it comes to designing the enclosure, there is no "standard" size. There is a wide variety of component manufacturers to choose from and this will usually impact the enclosure interior space requirements. In some case, co-located ITS devices may also share the same enclosure. This will further influence the design of the enclosure size.

Standard Specifications for an ITS enclosure can be found in Departmental publication 408 – ITS Device Special Provisions:

Resources

Section 1201 – Intelligent Transportation Systems Device Enclosure

8 POWER

8.1 Power Considerations

Generally, the key design steps for an ITS device deployment (electric) power system are:

- Determine the total power requirement
- Select a suitable power source based on availability
- Determine step-up/step-down transformer requirements, where applicable. The need for transformers will be based on voltage drop calculations
- Determine meter options. Where possible, arrange a flat rate fee with the electric utility provider.

8.1.1 Power Requirements

The total power requirement for any deployed device and/or deployment site is the sum of the following:

- The device(s) (e.g. DMS, CCTV camera, HAR transmitter, HAR beacons, detectors, signals, etc.)
- The controller cabinet components (refer to ITS Enclosure specification in Pub 408 Section 1230 for DMS and in Section 1201 for all other devices)

Select conductor and breaker sizes based on the “worst-case” scenario, in which all connected electric components are operating at full-capacity. Do not factor-in both devices for ancillary services which perform opposing services, and are not expected to operate simultaneously (e.g. heater and air-conditioner). For this preliminary sizing calculation, assume that the expected load drawn from the convenience outlet to be 12-amp at 120-volts.

A larger conductor size may be necessary to keep the voltage drop over long lengths to within the required 3%. (refer to Section 8.1.3)

See Table 8-1 for typical power requirements for each device. Listed power loads are for estimation purposes, actual power loads should be obtained from the related manufacturer(s).

Table 8-1: Typical Power Requirements (Device-Only, no enclosure)

DEVICE TYPE	POWER REQUIREMENT
CCTV	Typical
Camera without heater	~ 30 Watts
Camera with heater	~ 100 Watts
DMS (18" Amber LED characters)	Maximum / Typical
three 15-character lines, 15-degree view	2800 / 500 Watts
three 15-character lines, 30-degree view	3600 / 700 Watts
three 18-character lines, 15-degree view	3100 / 500 Watts
three 18-character lines, 30-degree view	4400 / 700 Watts
three 21-character lines, 15-degree view	3700 / 600 Watts
three 21-character lines, 30-degree view	4800 / 800 Watts
DMS (18" RGB LED characters) (Color)	Maximum / Typical
three 15-character lines, 30-degree view	4300 / 650 Watts
three 18-character lines, 30-degree view	5200 / 900 Watts
three 21-character lines, 30-degree view	6200 / 1300 Watts
HAR	Typical
HAR Transmitter antenna	~ 10 Watts
HAR Beacon Signal Set (LED)	~ 25 Watts
DETECTOR	Typical
Detector	~ 30 Watts
RAMP METER	Typical
Detector	~ 30 Watts
Signal Head (LED)	~ 25 Watts
Beacon (LED)	~ 25 Watts
TRAVEL TIME	Typical
Detector	~ 30 Watts

8.1.2 Power Availability

When electric power supply from a utility company is used for roadside ITS deployment, the most common power service is 240/120VAC, single-phase, 100A service.

The 240V/120A single-phase service is the most common service and is used for most ITS deployments. Higher voltage/amp service is used mainly on at collocated device locations, where multiple DMS or other devices with high power demand draw from the same power source.

Occasionally, a higher voltage/amp service is required when the point of service is located a significant distance from the ITS device. Along major interstates, it is often difficult to locate a device near a power source and still meet all the operational requirements. In this instance, the more robust power point of service might be established 1000’ or more from the deice, and a step up/step down transformer must be used between the service and the device. A voltage drop calculation must be performed by the designer in order to determine the appropriate means of supplying power to the site, which involves a step-up/step-down transformer.

Emergency means to disconnect power must be available within convenient distance from the powered device. In most DMS installations, the power needed to operate the DMS board (display portion of the DMS) is fed from the related DMS controller cabinet, and a power disconnect switch is usually installed outside the DMS controller cabinet. An additional power disconnect switch at the base of the DMS board support structure will not be necessary for such cases.

Although the electric utility company is required to provide electric power service where requested, it may do so by merely bringing the electric service to the edge of the user property, or in the case of ITS applications, the edge of related PennDOT right-of-way (ROW). The point where the service line of the electric utility company ends (the “service drop”), may be anywhere next to and/or along the edge of the ROW, within a “reasonable” distance of the ITS deployment. The definition of a “reasonable” distance is up to the interpretation of the planner assigned by the electric utility company, and is often affected by cost considerations. The Department is then responsible for all installations required to continue the electric service from the point of service drop, to the point of use. Where power metering is involved, the customer is required to provide the meter base at the point of service drop, excluding the power meter itself. It is often advantageous to include a field view with the Utility Unit as well as the Service Provider to determine up-front where power can be obtained from and where the utility company will provide a service drop to.

Once power supply is made available in the ITS device enclosure, the electric power must be converted to the voltage and format (AC or DC) as appropriate for the used electronic devices.

8.1.3 Voltage Drop

ITS deployment sites may sometimes be located at large distances from the intended power sources. A significant drop in available power voltage becomes an important consideration with large distances.

Given a fixed cable length (distance between an ITS deployment site and related power source), in order to keep the related voltage drop within the design limit, a designer has the choice of using larger power conductors, or transmitting the electric power over power cable at a higher voltage, which commonly involves using a step-up transformer near the power source, and a step-down transformer at the related ITS deployment site. This choice is often dominated by cost consideration.

General steps for designing power supply arrangements:

1. Determine the total power requirement (Watt or VA) for the whole cabinet, including devices which are powered from the cabinet.
2. Determine the required current (Amperes) that will flow through the power conductors, when all devices are operating at full capacity. In the case of 120V single-phase electric system, the current (I) is calculated as Total Power requirement (in VA) divided by the product of applicable power voltage and the power factor. Generally, a power factor of 0.8 is assumed, so the equation would be Power (VA) = Voltage (V) * Current (A) * Power Factor (0.8)
3. Look up the wire size from the applicable table in the NEC that has a higher ampacity rating than the current calculated above.
4. Voltage drop is calculated by using the following formula: The equation for calculating VD is:
   - VD=2*K*I*(D/CM) where:
   - K = 12.9 for copper wire and 21.2 for aluminum
   - I = Current
   - D = Distance
   - CM = Circular Mils of the wire (see NEC Chapter 9, Table 8)
5. Some of the utility power voltage is lost (voltage drop) through the power conductor. The longer the conductor, the higher the voltage drop. **Aim for a voltage drop of 3% or less.**
6. Make sure that the conduit is large enough for the power conductors. Per NEC, with 3 or more conductors, the total of cross section of all enclosed wires must be less than 40% of the actual cross section area of the conduit. Average cross section of conduit and wire of different sizes are listed in NEC.

8.1.4 Metering

In locations that do not use automatic meter reader (AMR) systems, safe, and convenient, meter reader access for utility personnel is an important consideration in selecting the deployment location. Roadways with small or no shoulders should not be considered for meter location. One way to circumvent this limitation is to arrange for non-metered (flat-rate) electric service through the utility company. However, this option is not necessarily available at all utility companies, and the ones that do support it often impose limitations on how the deployed systems may be designed and used.

Some AMR systems use short range radio-frequency (RF) communication systems, which allow drive-by meter data collection using mobile RF units. Some AMR systems use cellular data service, which allows utility offices to poll the meters from greater distances.

Considerations for meter reading access may no longer be necessary if an appropriate AMR system is available from the local utility company.

Coordinate with the power utility early in the design process to determine metering options. Consider the following power metering options:

- Metered, with safe and convenient personnel access
- Non-metered, flat usage rate
- Metered with AMR, using a drive-by RF data reader
- Metered with AMR, using a cellular data service.

8.2 Power Conditioning

Lightning spikes, transients and line noise will degrade electronic devices over time. Power conditioning provides protection from dirty power as well as regulating against sags (brownouts) and surges, thus reducing premature failure, improving equipment performance, and maintaining the uninterrupted operation of key equipment.

8.2.1 Voltage Surge Suppression

Lightning strikes are the most common cause of power surges to the ITS field system. The resulting voltage surges can propagate long distances along the cable to the connected devices. In order to protect the related ITS deployment, appropriate surge protection measures must be provided for the ITS devices. These measures can be broken down into 4 components:

- Lightning rods at the top of or near the support structure
- Grounding system, usually consisting of one or more grounding rods
- Surge suppression hardware in the control cabinet
- Grounding conductor bonding the three above components

The provision of lightning rods is preferred for deployments involving great heights, such as CCTV cameras and radio antenna at the top of tall poles, or DMS boards on structures that "stand out" among the surrounding landscape and vegetation. The use of lightning rod is usually omitted for deployments involving relatively low heights and where taller structures are present nearby.

In general, surge suppressors provide protection from energy (electric) surges by diverting and draining the excess (surge) energy to surrounding soil. It is therefore pertinent to combine the use of surge suppressors with a properly designed grounding conductor and a grounding system.

The provision of one or more lightning rods over the ITS device, in conjunction with a grounding conductor(s), can often help to divert the lightning discharges away from the field device assembly. Lightning abatement measures such as this are only effective if the lightning rod, related terminations, and the grounding conductors are sufficiently robust to conduct and to survive lightning discharges.

Provide lightning rods, grounding system, and diversion hardware for lightning discharge energy for all installations.

Telecommunications cables and sensor cables from nearby locations, just like the utility power cable, are subject to the same possibility of lightning strikes. The requirement for appropriate surge protection measures must therefore be extended to all cables brought into the enclosure of all ITS deployments.

A proper grounding arrangement must be provided at the support structure, and at the controller cabinet for the system. Where the controller cabinet is installed at or close to the base of the support structure, both the support structure and the cabinet may be bonded to the same grounding system.

It is important that the related grounding system is able to disperse the electric charge from the lightning strike quickly to the surrounding earth mass. This requirement is translated in the performance requirement on the grounding system to have "grounding resistance of 25 Ohms or less."

The industry standard is to use ¾-inch 10-foot solid copper (or copper-clad steel) ground rod for grounding. When multiple rods are needed to achieve the required maximum ground resistance (25 Ohms), space the ground rods at least as far apart from each other as the length of the rods.

Grounding rods, systems and testing procedures are specified in Pub 408 Section 1200 ITS General. The designer should assess the site environmental conditions to determine if the grounding system identified in the 408 is sufficient for the device location. Some devices require more robust grounding requirements, such as highly exposed HAR transmitters or CCTV cameras located at the tops of hills and mounted to high structures.

8.2.2 Uninterrupted Power Supply (UPS)

Frequent shutdowns and restarts of the electronic devices generally cause the electronic device to fail prematurely. Intermittent device shutdowns are generally triggered by low power-supply voltage, which are often the result of brief drops in supply voltage (brownouts) lasting seconds, and to lesser degrees complete power outage (blackouts) lasting more than a few minutes.

A UPS is required as part of the ITS Enclosure specification in Pub 408 Section 1201. The provision of a UPS is part of the power-supply arrangement to help bridge periods of short and intermittent drops in power voltages. Most commercial UPS products also include other desired features such as power conditioning. Power conditioning helps to filter out unwanted fluctuations in power quality and delivers “clean” power to the connected loads.

The 408 specification for UPS requires that the UPS be capable of powering all communications equipment in the cabinet, excluding the device itself, for a period of 30 minutes. UPS can also be used to bridge power outages at the site until repair crews can be called. In order to do this, coordinate with the District to determine the length of time necessary for a UPS to power the device location. Consideration should be given to any District maintenance contract response timeframes for system outages.

The following guidance must be followed when designing the UPS component of the power conditioning system:

- Is the UPS only required for the purposes of "power conditioning"; keeping the controller and communication interface in operation? If so, the 408 UPS Specification is adequate.
- The Department may consider additional back-up power requirements for critical devices (e.g. along key detour routes)
- For DMS installations, a generator would be more suitable to keep the device operational

8.3 Solar 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 power is an option. Factors include:

- Amount of power the system needs
- Percent of time the system is operating (such as beacons that only flash upon certain infrequent events)
- The amount of time the system must operate in the absence of any sunlight
- The geographic location, which affects the amount of sunlight received

A solar power system is typically comprised of solar panels, a battery bank, cabling, and a power convertor/charging system that converts power generated from the solar panel to storage, and then converts this battery power to the connected operating loads. A solar power system such as this may be used as a stand-alone power source, or as a supplement to installations where the electric power, from the utility company, is only available during part of the day (such as the case with a highway lighting circuit which is collectively controlled based on a day-light sensor or timer).

A solar power system may only be used in areas where sufficient sun light is generally available. Solar power systems must therefore not be used for areas with less than three 8-hour sun lit periods per week. If the longitude and latitude coordinates of the deployment site are known, related average insulation data can be acquired from the NASA Surface Meteorology and Solar Energy (SSE) division through its web site at:

http://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?uid=1.

In order to receive the maximum amount of sunlight each day and throughout the year, deployment sites in the Northern Hemisphere must include solar panels oriented to face south. The inclination of the solar panel(s) should roughly correspond to the latitude of related deployment site. As an example, the solar panels used near Philadelphia (approximate latitude 39.9N) should be mounted at approximately 39.9 degrees from the azimuth, facing south.

The battery bank and the solar-panel assembly of a solar power system must be of sufficient sizes to support full operation of the connected loads for a minimum of 24 hours for applications where daily maintenance service is performed, and for a minimum of seven days for other conditions.

Due to the above sizing requirements, the use of a solar power system is generally limited to devices requiring 100 Watts or less to operate. Devices requiring higher wattage for brief periods only may also be considered. In all cases, credible solar-panel and battery sizing calculations for related loads, at all expected usage patterns, must be required from the system provider prior to acceptance of the related design.

Devices which are potential/feasible candidates for solar power are:

- HAR beacons
- HAR Transmitters
- Detectors
- Portable devices (HAR, Detectors, DMS)
- CCTV cameras (typically portable) that do not include a heater

Typical battery voltage used in ITS deployments is 12 Volts per unit; if higher voltages are needed, the simplest way to achieve it is by connecting batteries in series. Where feasible, choose a voltage equal to a whole number multiplied by 12 Volts (e.g. 12V, 24V, 36V, 48V etc) as the main operating voltage of the device enclosure.

Require the system supplier to provide credible solar-panel and battery sizing calculations for the supported loads, at all expected usage patterns prior to acceptance of the related design.

Foliage grown over the solar panel reduces the amount of solar energy received by the solar panels. Foliage that obstructs solar panels must be trimmed. Such trimming must be repeated at least once a year, especially in the summer.

Energy-delivery performance of the batteries diminishes at extreme high and low temperatures, and as a result of rapid temperature swings. Ensure that explicit mechanical measures are provided to isolate the batteries from extreme ambient temperatures.

Note that solar power should ONLY be used as a last resort; use it where power points of service are extremely expensive, or where there is no power available. Perform detailed calculations to determine the required load of the device and the appropriate number of batteries. Obtain explicit approval from the District Representative prior to proceeding with a solar installation.

8.4 Optional Back-Up Power Generator

Consider adding a provision for an ITS deployment to include the means of accepting power from a mobile generator as an alternate, temporary power source. This provision usually involves the following:

- A twist-lock power receptacle behind a lockable window to accept the power cord from this alternate power source
- A selector switch behind the lockable window that allows the choice between regular and alternate power sources
- A notch at the lower edge of the lockable window to allow passage of the extension cord with the window closed and locked

8.5 Utility Billing

In the majority of ITS construction projects, the utilities are set-up in the contractor's name, since the ownership of the device/system resides with the contractor until the project is complete. Once the 60-day Operational Test has been conducted and accepted, ownership and billing will be transferred from the Contractor to the Department.

These utility subscription accounts must be transferred officially and properly to PennDOT when the period for which the contractor is responsible expires. Such transfers may require official endorsement by the existing account holder, and therefore cannot be arranged by PennDOT, even though the latter may be more expedient. At this stage, the contractor is usually most interested in receiving the related payment, so small outstanding contract scopes such as transferring the account may be forgotten.

Include submission of documented proof of official transfers (to PennDOT) of subscription to power, communication, and other utility services as a payment condition for the related contract phase.

In order to ensure that the transfer of the utility subscription account is completed in an expedient manner, documented proof of such transfers could be included as a payment condition for the related contract phase.

9 COMMUNICATION

9.1 Communication Design Considerations

Generally, the key design considerations for Center-to-Field (C2F) communications system for an ITS deployment are:

- Determine the required communications characteristics, mainly the required bandwidth (in Kbps or Mbps)
- Investigate what telecommunication options are available at/near the planned deployment site(s)
- Coordinate with the District to ensure that their requirements are being met
- If using public infrastructure, confirm with telecommunication service providers that the required communications service is available at the deployment location
- When using 3rd party telecommunications options, the District Representative must perform all coordination to establish the connection through the statewide contract. The District coordinates with PennDOT BIO to establish these connections
- Compare the related costs, benefits, security aspects of different communications options. Select a suitable communications means based on the options available at the deployment site
- Incorporate the chosen communication means into the overall design
- Communications routed through the public WWW are acceptable only on a case-by-case basis. Any connection using public WWW must be coordinated through and accepted by PennDOT BIO for security reasons.

9.2 Device/System Characteristics and Requirements

Each ITS system brings with it particular communication needs. The communication pattern and bandwidth requirement are the two key factors in evaluating what the system device needs to operate effectively.

Table 9-1 contains the typical bandwidth requirements for various ITS devices. These requirements must be accommodated by the selected communications medium.

Table 9-1: Typical ITS System Communication Requirements

System Type	Typical Usage Pattern	Required Bandwidth Range
CCTV Camera	Continuous	386 Kbps to 1.544 Mbps (1/4 Fractional T-1 to Full T-1)
DMS	Periodic, intermittent, short bursts	9.6 Kbps to 56 Kbps
HAR	Periodic, intermittent, short bursts	9.6 Kbps to 56 Kbps
Vehicle Detector	Intermittent, short bursts	9.6 Kbps to 115 Kbps
Ramp Meter System	Periodic, intermittent, short bursts	9.6 Kbps to 56 Kbps
Travel Time System Detector	Intermittent, short bursts	9.6 Kbps to 115 Kbps

9.2.1 Communication Patterns (Intermittent vs. Continuous)

With the notable exception of CCTV cameras, a typical communications session between an ITS device controller and the TMC usually involves a small amount of data (3 Kilobits or less). Such communications sessions take place only when specific needs arise, or are scheduled on a periodic basis, typically every ten minutes or longer. A communications session with such transmission content, and with such a usage pattern, can easily be supported by low-bandwidth communications means with bandwidth of 9.6 Kbps to 56 Kbps (such as that afforded with voice-grade dial-up telephone services). Due to the long pauses between communications sessions, the communication connection does not need to be engaged all the time (always on); a “dial-up” arrangement will usually suffice.

CCTV cameras (unless being used to transmit strictly still images) will require an always-open, continuous communication session and the means to support the relatively large communications bandwidth is required for the transmission of the video image. A full T-1 (1.544 Mbps) service is typically used for video transmission to the TMC, though lower bandwidths (such as ¼ T1) could be used for video streams with low frame rate (frames-per-second).

9.3 Availability

Potential Center to field (C2F) communication arrangements that are appropriate for ITS systems are:

- Fiber optic cable, owned or leased
- POTS (Plain Old Telephone Service), dial-up, voice-grade, land-line telephone service
- Leased land-line, telephone cable with Frame-relay service at fractional T-1 or full T1 capacity
- Broadband radio, data radio system involving WiMAX or proprietary radio-Frequency (RF) technologies
- Broadband cellular, data service with IP routing solely through cellular data transceivers (modems)
- Broadband cellular, data service with IP routing through the server farm (via public internet)
- Satellite internet, data service through commercial service provider

Data services provided commercially by others are generally available in and around major population centers; availability for rural area may be limited to areas along major arterials and larger population centers.

Availability of a service is not limited to just the availability of existing infrastructure to extend to the deployment sites, but also for an actual usable transmission session when the need for such transmission arises. Commercial communications services which are "shared use" in nature are very much affected by usage surges which are typical during and near places of major events or calamity.

Table 9-2: ITS System Communication Capacity

Communication Method	Typical Available Bandwidth
Fiber optic cable	Up to 40 Gbps per carrier light wavelength
POTS	54 Kbps
Leased land-line	Fractional (1/4 or 1/2) T1, full T1 (1544 Kbps), T3 (28 T1s)
Broadband radio	Up to 100 Mbps, depending on technology used
Broadband cellular	Up to 4 Mbps, depending on service plan
Satellite internet	Up to 5 Mbps depending on service plan

Every potential communication option presents unique capabilities, risks, and limitations. Below is a summary of the major design considerations, advantages, and disadvantages of each.

Any communication option that involves a third party provider (i.e. is not part of PennDOT's private WAN or fiber optic networks) must be coordinated and established by the District

Representative through the statewide contract. For all IP based communications systems, the designer or contractor MUST coordinate with BIO to determine network configuration parameters, including IP address assignment.

9.3.1 Fiber Optic Cable

Design Considerations:

- Verify that the cable installation through the intended route is feasible, and does not require extreme challenges such as crossing wide ravines.

Advantages:

- Virtually unlimited bandwidth
- No danger of voltage surges

Disadvantages:

- Potential difficulties in achieving clear Right-of-Way for installation
- High installation cost of cable

9.3.2 POTS (Plain Old Telephone Service)

Design Considerations:

- Verify that the cable installation through the intended route is feasible, and does not require extreme challenges such as crossing wide ravines.

Advantages:

- Very widely used and understood in ITS deployments
- Generally inexpensive
- Widely available

Disadvantages:

- Limited to low ($\leq$ 54 Kbps) bandwidth applications
- Extension of utility infrastructure (e.g. poles) can be expensive
- Usage surges may affect service and availability
- Does not provide “always on” capability. Connection initiation can be time consuming

9.3.3 Broadband Radio Service

Design Considerations:

- Except for short-range paths that can be visually evaluated, a path study, performed by a communications consultant or a system integrator, is recommended for new installations. A path study predicts the signal strength, reliability, and fade margin of a proposed radio link. While terrain, elevation, and distance are the major factors in this process, a path study must also consider antenna gain, feed line loss, transmitter power, and receiver sensitivity to arrive at a final prediction.

Advantages:

- High bandwidth (up to 100 Mbps, depending on technology used)
- Low infrastructure costs

Disadvantages:

- A clear transmission path is not always possible
- Requires a RF license application/acquisition, unless license-exempt RF bands are used
- Frequent, periodic tree-trimming may be required to maintain clear line-of-sight

9.3.4 Broadband Cellular Data Service

Design Considerations:

- Cellular system coverage outside of population centers typically is focused along major arterial roads, which coincides roughly with areas where the need for ITS deployments may be the greatest.
- Verify that there is adequate cellular signal strength available at the planned deployment site. This may simply involve using portable computer equipped with compatible wireless adaptor module and antenna to measure signal strength, and confirm upload bandwidth.

Advantages:

- Allows much flexibility in the planning of device deployment sites
- Available in about 95% of Pennsylvania Interstate lane-miles
- Antenna height does not have to be very tall
- Low set-up and infrastructure costs

Disadvantages:

- Availability of data channels is low in/near densely populated areas
- Availability affected by usage surges
- Where data transmission is routed through public domain, significant security measures are required
- Recurring costs incurred

9.3.5 Satellite Internet

Design Considerations:

- Verify that there is adequate satellite data signal strength available at the planned deployment site. This may involve using portable computer equipped with compatible wireless adaptor module and antenna to measure signal strength, and confirm upload bandwidth.

Advantages:

- Available practically everywhere
- Installation costs are negligible

Disadvantages:

- Availability affected by usage surges
- Signal quality affected by weather events
- Significant security measures necessary
- Line of sight with satellites required – tree trimming may be necessary

9.4 Coordination with PennDOT BIO

Any planned public telecommunication options must be coordinated through PennDOT's BIO.

For any IP based communications systems, such as the use of Ethernet, the designer must coordinate with BIO to assign the appropriate IP addresses and determine the proper network configuration settings.

Some of the communications options involve routing data through public internet. Passage through the public domain makes all the data prone to unwanted/unauthorized access by others. Uses of such communications means have been approved in several Districts on a case-by-case basis, with involvement of Bureau of Infrastructure and Operations (BIO). Consult BIO for compliance issues with the Office of Administration (OA) ITBs when the considered data communications method involves routing through the "public" internet.

10 Appendix A – Design Checklists

10.1 CCTV Design Checklist

Detection Purpose	YES	NO	N/A
• Is this deployment consistent with "needs" outlined in a Concept of Operations or Regional Operations Plan?	☐	☐	☐
• Is this deployment consistent with the ITS architecture?	☐	☐	☐
Location/Placement Guidelines	**YES**	**NO**	**N/A**
• Has the camera location been chosen/designed with consideration to maximizing visibility?	☐	☐	☐
• Has a site for the camera been chosen that considers the available utilities and the cost/constraints associated with connection to those utilities?	☐	☐	☐
• Has the site been chosen with consideration to protecting the camera structure and ensuring that it will last; without undue maintenance necessary to the structure and the surrounding site?	☐	☐	☐
• Has a site been chosen that makes the best use of the operational needs of a CCTV camera system (e.g. Incident Management)?	☐	☐	☐
• Has a site been chosen that satisfies safety requirements for personnel performing maintenance on the system?	☐	☐	☐
• Has the site been chosen so that it will minimize maintenance costs (e.g. there is sufficient shoulder to park a bucket truck without the need for a full lane closure and significant MPT)?	☐	☐	☐
CCTV Type	**YES**	**NO**	**N/A**
• Is the camera type (external vs. dome) appropriate for the desired location and application?	☐	☐	☐
• Does the District require the camera to be compatible with a legacy analog system?	☐	☐	☐
Camera Mount	**YES**	**NO**	**N/A**
• Have Department standards ITS-1000M and ITS-1002M been followed in the design of the mount/structure?	☐	☐	☐

Enclosure	YES	NO	N/A
• Is an enclosure required at this location?	☐	☐	☐
• Can personnel safely access the enclosure?	☐	☐	☐
• Is the enclosure located within 150 feet of the camera?	☐	☐	☐
• Is the enclosure mounted on the camera pole or on an existing structure (where possible)?	☐	☐	☐
• Does the location and orientation provide adequate protection for the enclosure?	☐	☐	☐
• Has a concrete maintainer's pad been provided at the enclosure's main door?	☐	☐	☐
Power Requirements	**YES**	**NO**	**N/A**
• Have the power requirements for the camera and all of the system components been determined?	☐	☐	☐
Power Availability	**YES**	**NO**	**N/A**
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the camera site?	☐	☐	☐
• Have Step-Up/Step-Down requirement calculations been performed?	☐	☐	☐
• Have the metering options been determined?	☐	☐	☐
Power Conditioning	**YES**	**NO**	**N/A**
• Do the standard grounding specifications meet the needs of the system?	☐	☐	☐
• Have the UPS and power back-up options been determined and accounted for?	☐	☐	☐
Communication	**YES**	**NO**	**N/A**
• Have the communication requirements for the camera been determined?	☐	☐	☐
• Has an appropriate communication infrastructure been located and confirmed within a reasonable proximity to the site?	☐	☐	☐
• If there are multiple communication options, have the pros/cons been studied?	☐	☐	☐
• If using public communications infrastructure, has service been coordinated with PennDOT BIO and the District?	☐	☐	☐

Environmental	YES	NO	N/A
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	☐	☐	☐

10.2 DMS Design Checklist

Pre-Design Planning	YES	NO	N/A
• Is this deployment consistent with “needs” outlined in a Concept of Operations or Regional Operations Plan?	☐	☐	☐
• Is this deployment consistent with the ITS architecture?	☐	☐	☐
Longitudinal Placement	**YES**	**NO**	**N/A**
• Is the DMS visible and un-obscured?	☐	☐	☐
• Is the DMS placed sufficiently in-advance of any interchanges that would be used for diversions?	☐	☐	☐
• Is the DMS properly spaced away from existing guide signs?	☐	☐	☐
Lateral Placement	**YES**	**NO**	**N/A**
• Is the DMS structure located beyond the clear zone or protected by a suitable safety barrier?	☐	☐	☐
• Has the lateral offset of the DMS been accounted-for when calculating the length of the Reading and Decision Zone?	☐	☐	☐
Vertical Placement	**YES**	**NO**	**N/A**
• Is the approaching segment of roadway relatively flat (between 0-4% vertical grade)	☐	☐	☐
Sign Matrix Type	**YES**	**NO**	**N/A**
• Has a sign matrix type been chosen that is consistent with the visibility and message requirements of the roadway being deployed on?	☐	☐	☐
Sign Viewing Angle	**YES**	**NO**	**N/A**
• Has a sign viewing angle been chosen that complements the roadway alignment and the DMS structure?	☐	☐	☐
Sign Access	**YES**	**NO**	**N/A**
• Are there any traffic, environmental, or safety factors that warrant a specific type of sign access?	☐	☐	☐
Structure	**YES**	**NO**	**N/A**
• Have visibility, road speed/volume, right-of-way, and maintenance/cost issues all been considered when selecting a type of sign structure?	☐	☐	☐
• Is there sufficient vertical clearance for the sign and the structure?	☐	☐	☐

Enclosure	YES	NO	N/A
• Can personnel safely access the enclosure? • Is the enclosure located within a reasonable distance of the sign?	☐	☐	☐
• Is the sign face visible from the enclosure location?	☐	☐	☐
• Does the location and orientation provide adequate protection for the enclosure?	☐	☐	☐
Power Requirements	**YES**	**NO**	**N/A**
• Have the power requirements for the DMS and all of the system components been determined?			
Power Availability	**YES**	**NO**	**N/A**
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the DMS site?	☐	☐	☐
• Have Step-Up/Step-Down requirement calculations been performed?	☐	☐	☐
• Have the metering options been determined?	☐	☐	☐
Power Conditioning	**YES**	**NO**	**N/A**
• Do the standard grounding specifications meet the needs of the system?	☐	☐	☐
• Have the UPS and power back-up requirements been determined and accounted for?	☐	☐	☐
Communication	**YES**	**NO**	**N/A**
• Have the communication requirements for the DMS been determined?	☐	☐	☐
• Has an appropriate communication infrastructure been located and confirmed within a reasonable proximity to the site?	☐	☐	☐
• If there are multiple communication options, have the pros/cons been studied?	☐	☐	☐
• If using public communications infrastructure, has service been coordinated with PennDOT BIO and the District?	☐	☐	☐
Environmental	**YES**	**NO**	**N/A**
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	☐	☐	☐

10.3 HAR Design Checklist

Pre-Design Planning	YES	NO	N/A
• Is this deployment consistent with "needs" outlined in a Concept of Operations or Regional Operations Plan?	☐	☐	☐
• Is this deployment consistent with the ITS architecture?	☐	☐	☐
Control Software	**YES**	**NO**	**N/A**
• Is the HAR compatible with the existing device control software?	☐	☐	☐
Site Selection	**YES**	**NO**	**N/A**
• Are there any adjacent existing HAR systems, and if so, has coordination taken place with them?	☐	☐	☐
• Has a frequency search taken place?	☐	☐	☐
• Has an onsite listening survey been performed?	☐	☐	☐
• Has reception of the NOAA All-Hazards Alert System been verified?	☐	☐	☐
• If in an urban setting, have existing traveler information stations (e.g. AM news radio) been considered when justifying the new HAR placement?	☐	☐	☐
Transmitter Location	**YES**	**NO**	**N/A**
• Is the potential transmitter site free of significant vertical (25' or higher) obstructions?	☐	☐	☐
• Is power (120VAC) and communication (telephone) service available at the site?	☐	☐	☐
• Is there sufficient open ground (at least 40' x 40') for the cabinet and antenna installation?	☐	☐	☐
• If there are adjacent HAR transmitters, has message synchronization been built into the design?	☐	☐	☐
Beacon Sign Location	**YES**	**NO**	**N/A**
• Have MUTCD sign standards been followed?	☐	☐	☐
• Are the signs visible and unobstructed?	☐	☐	☐
• Is the sign placed such that a motorist is entering the proposed broadcast range of the HAR transmitter?	☐	☐	☐

• Does the location of the sign permit the traveler to safely tune and then react to the message?	☐	☐	☐
• Are the signs placed sufficiently in-advance of any interchanges that serve detour routes?	☐	☐	☐
• Is it possible to collocate the sign/beacon with an existing CCTV camera for the purpose of visual verification?	☐	☐	☐
Licensing and Permits	**YES**	**NO**	**N/A**
• Has consideration been given to other HAR transmitters (not adjacent to the new site) along a particular route so that the same frequency can be used?	☐	☐	☐
ITS Enclosure (applies to both the transmitter location and the beacon location(s))	**YES**	**NO**	**N/A**
• Can personnel safely access the enclosure?	☐	☐	☐
• Is the enclosure located within 150 feet of the device?	☐	☐	☐
• Does the location and orientation provide adequate protection for the enclosure?	☐	☐	☐
Power Requirements	**YES**	**NO**	**N/A**
• Have the power requirements for the HAR and all of the system components been determined?	☐	☐	☐
Power Availability	**YES**	**NO**	**N/A**
• Have the power requirements for all of the system components been determined?	☐	☐	☐
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the detector site?	☐	☐	☐
• Have Step-Up/Step-Down requirement calculations been performed where necessary?	☐	☐	☐
• Have the metering options been determined?	☐	☐	☐
Power Conditioning	**YES**	**NO**	**N/A**
• Do the standard grounding specifications meet the needs of the system?	☐	☐	☐
• Have the UPS and power back-up options been determined and accounted for?	☐	☐	☐

Communications	YES	NO	N/A
• Have the communication requirements for the HAR been determined?	☐	☐	☐
• For wired communication, has an appropriate source been located and confirmed within a reasonable proximity to the site?	☐	☐	☐
• For cellular communication, has the required signal strength been verified at the site? • If there are multiple communication options, have the pros/cons been studied?	☐	☐	☐
• If using public communications infrastructure, has service been coordinated with PennDOT BIO and the District?	☐	☐	☐
Environmental	**YES**	**NO**	**N/A**
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	☐	☐	☐

10.4 Vehicle Detector Design Checklist

Detection Purpose	YES	NO	N/A
• Is this deployment consistent with "needs" outlined in a Concept of Operations or Regional Operations Plan?	☐	☐	☐
• Is this deployment consistent with the ITS architecture?	☐	☐	☐
System Needs	**YES**	**NO**	**N/A**
• Does the detector deployment satisfy the precision considerations established in the system needs?	☐	☐	☐
• Does the detector deployment satisfy the spacing considerations established in the system needs?	☐	☐	☐
• Does the detector deployment satisfy the accessibility considerations established in the system needs?	☐	☐	☐
Detector Technology Selection	**YES**	**NO**	**N/A**
• Does the detector technology satisfy the accuracy, accessibility, and cost requirements established in the system needs?	☐	☐	☐
Deployment Guidelines	**YES**	**NO**	**N/A**
• Does the detector deployment take steps to minimize new structures and collocate devices where possible?	☐	☐	☐
• Does the detector deployment include sufficient detector coverage to satisfy system needs?	☐	☐	☐
Enclosure	**YES**	**NO**	**N/A**
• Is an enclosure required at this location?	☐	☐	☐
• Can personnel safely access the enclosure?	☐	☐	☐
• Is the enclosure located within 150 feet of the detector?	☐	☐	☐
• Is the enclosure mounted on an existing structure (where possible)?	☐	☐	☐
• Does the location and orientation provide adequate protection for the enclosure?	☐	☐	☐
• Has a concrete maintainer's pad been provided at the enclosure's main door?	☐	☐	☐

Power Requirements	YES	NO	N/A
• Have the power requirements for the detector and all of the system components been determined?	☐	☐	☐
Power Availability	**YES**	**NO**	**N/A**
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the detector site?	☐	☐	☐
• Have Step-Up/Step-Down requirement calculations been performed?	☐	☐	☐
• Have the metering options been determined?	☐	☐	☐
Power Conditioning	**YES**	**NO**	**N/A**
• Do the standard grounding specifications meet the needs of the system?	☐	☐	☐
• Have the UPS and power back-up options been determined and accounted for?	☐	☐	☐
Communication	**YES**	**NO**	**N/A**
• Have the communication requirements for the detector been determined?	☐	☐	☐
• Has an appropriate communication source been located and confirmed within a reasonable proximity to the site?	☐	☐	☐
• If there are multiple communication options, have the pros/cons been studied?	☐	☐	☐
• If using public communications infrastructure, has service been coordinated with PennDOT BIO and the District?	☐	☐	☐
Environmental	**YES**	**NO**	**N/A**
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	☐	☐	☐

10.5 Ramp Meter Design Checklist

Pre-Design Planning	YES	NO	N/A
• Is this deployment consistent with "needs" outlined in a Concept of Operations or Regional Operations Plan?	☐	☐	☐
• Is this deployment consistent with the ITS architecture?	☐	☐	☐
Ramp Meter Study	**YES**	**NO**	**N/A**
• Has a comprehensive Ramp Meter Study been performed?	☐	☐	☐
• Do the results of the study support continuing with the deployment project?	☐	☐	☐
Lane Configuration	**YES**	**NO**	**N/A**
• Do the number of lanes and the vehicles per green design support the projected ramp volume?	☐	☐	☐
Ramp Meter Location	**YES**	**NO**	**N/A**
• Is the meter placed such that enough stacking space is available on the ramp to accommodate the queues it will generate?	☐	☐	☐
• If the ramp meter consists of more than one lane, does it provide a sufficient distance for the lanes to merge prior to the merge with the mainline?	☐	☐	☐
Ramp Meter Signals	**YES**	**NO**	**N/A**
• Are the signals vertically spaced such that the driver can see the signal heads while parked at or just in front of the stop bar?	☐	☐	☐
• Are the signals designed in compliance with MUTCD Sections 4D and 4H?	☐	☐	☐
• Are the signals designed in compliance with FHWA requirements for Mast Arm Signal Poles, Signal Placement, and Signal Heads?	☐	☐	☐
Vehicle Detectors	**YES**	**NO**	**N/A**
• Does the system design include all of the necessary detection areas; Demand, Ramp Queue, and Mainline?	☐	☐	☐
• Does the complexity/configuration of the system require the additional detection area; Passage, Exit Ramp, and Entrance Ramp?	☐	☐	☐

Signing and Pavement Markings	YES	NO	N/A
• Do the signs and marking meet the MUTCD standards in Sections 2B.56, 2C.37, and 4I?	☐	☐	☐
Enclosure Placement	**YES**	**NO**	**N/A**
• Is an enclosure required at this location?	☐	☐	☐
• Can personnel safely access the enclosure?	☐	☐	☐
• Is the enclosure located within 150 feet of the detectors?	☐	☐	☐
• Is it positioned such that maintenance personnel can access the enclosure while viewing ramp meter signal heads?	☐	☐	☐
• Is the enclosure mounted on an existing structure (where possible)?	☐	☐	☐
• Does the location and orientation provide adequate protection for the enclosure?	☐	☐	☐
• Has a concrete maintainer's pad been provided at the enclosure's main door?	☐	☐	☐
Power Requirements	**YES**	**NO**	**N/A**
• Have the power requirements for the detector and all of the system components been determined?	☐	☐	☐
Power Availability	**YES**	**NO**	**N/A**
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the detector site?	☐	☐	☐
• Have Step-Up/Step-Down requirement calculations been performed?	☐	☐	☐
• Have the metering options been determined?	☐	☐	☐
Power Conditioning	**YES**	**NO**	**N/A**
• Do the standard grounding specifications meet the needs of the system?	☐	☐	☐
• Have the UPS and power back-up requirements been determined and accounted for?	☐	☐	☐

Communications	YES	NO	N/A
• Have the communication requirements for the detector been determined?	☐	☐	☐
• Has an appropriate communication source been located and confirmed within a reasonable proximity to the site?	☐	☐	☐
• If there are multiple communication options, have the pros/cons been studied?	☐	☐	☐
• Has the chosen communications option been reviewed by BIO?	☐	☐	☐
• If using public communications infrastructure, has service been coordinated with PennDOT BIO and the District?	☐	☐	☐
Environmental	**YES**	**NO**	**N/A**
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	☐	☐	☐

10.6 Travel Time System Design Checklist

Pre-Design Planning	YES	NO	N/A
• Is this deployment consistent with "needs" outlined in a Concept of Operations or Regional Operations Plan?	☐	☐	☐
• Is this deployment consistent with the ITS architecture?	☐	☐	☐
• Have DMS display capabilities been considered in selecting the reporting needs?	☐	☐	☐
Data Ownership/Acquisition	**YES**	**NO**	**N/A**
• Have departmental capabilities, reporting needs, funding, data quality, and existing infrastructure been considered in deciding data ownership/acquisition?	☐	☐	☐
Detection Method	**YES**	**NO**	**N/A**
• If an RTVD system has been selected; has a penetration study been completed?	☐	☐	☐
• Has RTVD or point vehicle detection been selected?	☐	☐	☐
o If not, has a plan for data capture and verification been created?	☐	☐	☐
• Has a cost effective detection method been selected?	☐	☐	☐
Detector Placement	**YES**	**NO**	**N/A**
• Have the reporting needs been used in selecting the locations to be monitored?	☐	☐	☐
• Have the DMS display capabilities been used to determine the number of travel time destinations?	☐	☐	☐
• Do the selected locations conform to spacing requirements?	☐	☐	☐
• Are existing structures, power, and communications being used wherever possible?	☐	☐	☐
• Are all field devices protected by guiderail and/or located outside of roadway clear zone?	☐	☐	☐
• Are devices located in such a way that they are accessible to maintenance staff?	☐	☐	☐

Enclosure	YES	NO	N/A
• Is an enclosure required at this location?	☐	☐	☐
• Can personnel safely access the enclosure?	☐	☐	☐
• Is the enclosure located within 150 feet of the detector?	☐	☐	☐
• Is the enclosure mounted on an existing structure (where possible)?	☐	☐	☐
• Does the location and orientation provide adequate protection for the enclosure?	☐	☐	☐
• Has a concrete maintainer's pad been provided at the enclosure's main door?	☐	☐	☐
Power Requirements	**YES**	**NO**	**N/A**
• Have the power requirements for the detector and all of the system components been determined?	☐	☐	☐
Power Availability	**YES**	**NO**	**N/A**
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the detector site?	☐	☐	☐
• Have Step-Up/Step-Down requirement calculations been performed?	☐	☐	☐
• Have the metering options been determined?	☐	☐	☐
Power Conditioning	**YES**	**NO**	**N/A**
• Do the standard grounding specifications meet the needs of the system?	☐	☐	☐
• Have the UPS and power back-up options been determined and accounted for?	☐	☐	☐
Communication	**YES**	**NO**	**N/A**
• Have the communication requirements for the detector been determined?	☐	☐	☐
• Has an appropriate communication source been located and confirmed within a reasonable proximity to the site?	☐	☐	☐
• If there are multiple communication options, have the pros/cons been studied?	☐	☐	☐
• If using public communications infrastructure, has service been coordinated with PennDOT BIO and the District?	☐	☐	☐

Environmental	YES	NO	N/A
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	☐	☐	☐