TSMO Design and Integration Guidelines

Version 1.0

Bureau of Maintenance and Operations
PennDOT District 6-0

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APPENDICES

Appendix A – Systems Engineering Report Examples

Appendix B – Travel Time Memo Example

Appendix C – Task H Spreadsheet Template

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Acronyms

ATMS	Advanced Transportation Management System
BIO	Bureau of Infrastructure and Operations
BOMO	Bureau of Maintenance and Operations
BR	Bluetooth Reader
CCTV	Closed Circuit Television
ConOps	Concept of Operations
DFV	Design Field View
DMS	Dynamic Message Sign
ECMS	Electronic Construction Management System
FDOM	Final Design Office Meeting
FHWA	Federal Highway Administration
ITS	Intelligent Transportation Systems
PDA	Pre-Determined Amount
PennDOT	Pennsylvania Department of Transportation
PS&E	Plans, Specifications & Estimate
RTMC	Regional Transportation Management Center
SER	Systems Engineering Report
TS&L	Type, Size and Location Plans
TTS	Travel Time Sensor
UAT	User Acceptance Test
VMS	Video Management System

1. INTRODUCTION

1.1 Purpose of the Guide

The intent of this guide is to serve as a reference to design consultants, contractors, and network integrators on key items that should be considered during the various phases of a PennDOT Intelligent Transportation Systems (ITS) design project for successful integration of ITS devices into PennDOT's Advanced Traffic Management System (ATMS) software platform and/or PennDOT's Video Management System (VMS). It is critical that the ITS design and construction teams coordinate with PennDOT Bureau of Infrastructure and Operations (BIO) during all phases of the project to mitigate potential delays.

This guide will focus on projects that include the following:

- Typical ITS System Deployments – Already-established devices being considered and deployed in a project.
    - Design – **Figure 2-1**
    - Integration – **Figure 3-1**
        - Closed Circuit Television (CCTV) cameras
        - Changeable Message Signs (CMS) also known as Dynamic Message Signs (DMS) or Variable Message Signs (VMS)
        - Detection Systems
        - Data and Video Feeds
        - Traffic Signals

- New ITS System Deployments – New TSMO strategies being considered and deployed in a project.
    - Design – **Figure 2-2**
    - Integration – **Figure 3-2**

- ATMS Modifications/Enhancements – ATMS platform adjustments.
    - Design – **Figure 2-3**
    - Integration – **Figure 3-3**

1.2 Intended Audience

This guide is directed at all individuals involved in the design, deployment, and integration of ITS devices for PennDOT: PennDOT Bureau of Maintenance and Operations (BOMO), BIO, District IT and ITS staff, design consultants, contractors, and network integrators.

1.3 Regional Architecture

It should be noted that all ITS design projects should be completed in accordance with the PennDOT regional ITS architecture. This guide will not cover the specifics of each regional ITS architecture. PennDOT expects that the project designer evaluate the regional architecture during the systems engineering phase and incorporate all necessary requirements in the overall design.

1.4 General PennDOT OA Coordination

General Guidance

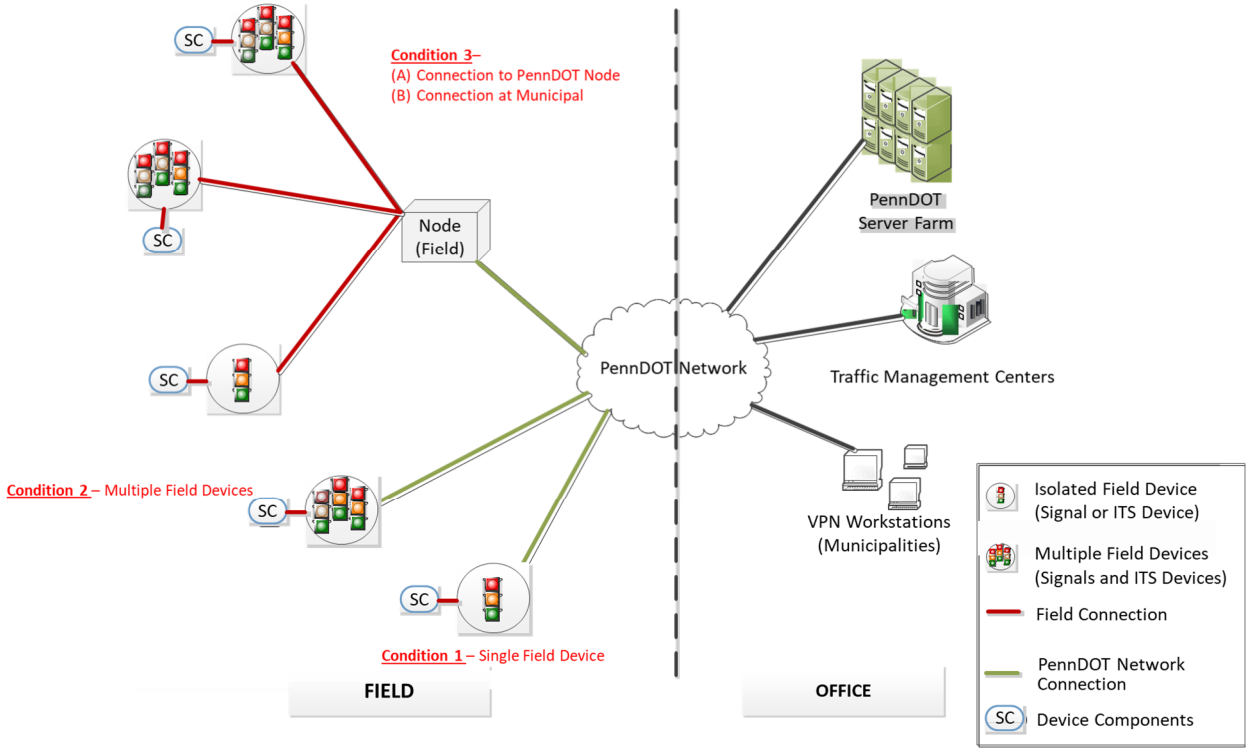
- No direct Fiber connects into the Commonwealth Network. They need to have networks in place that are capable of connecting directly to COPA over a secure VPN.
- Desired video or other data from outside partners, including municipalities, needs to be brought back to a single headend location. These head ends will be connected to the OA business partner network via a secure VPN.
- Districts should not be purchasing or specifying Cisco 800 Series Routers, other VPN routers, or anything else that relies on connecting devices over the public internet to the Commonwealth Network.
- Existing Cisco 800 Series Routers that have been already purchased and are in the process of being integrated should contact BIO to determine the appropriate solution moving forward.
- Direct connections of field devices (including traffic signals) back to the Commonwealth Network should be on a secure network such as a T1 Line. Cellular devices should not be leveraged for the streaming of video.

Network Connection Types

Figure 1-1 presents the following Network Connection Types:

- **Condition 1** is the connection of single isolated field devices back to PennDOT Network
- **Condition 2** is the connection of multiple field devices back from a single field connection back to PennDOT Network
- **Condition 3 (A)** is the connection of multiple field devices back from PennDOT Node device back to the PennDOT Network
- **Condition 3 (B)** is the connection of multiple field devices back to a Municipal Location that will then be sent back to the PennDOT Network through the OA Business Partner Access Point.

Figure 1-1: Network Connection Types



Construction Deployment Options

- **Option 1 – PennDOT-Owned Equipment and Connecting Back to PennDOT** [PennDOT and Business Partners working on our behalf access the cabinet]
    - All Conditions back Permitted
    - PennDOT IT approved ISR Router to connect back to the Commonwealth Network.
    - Commonwealth Network connection through the PennDOT telecom contract.

- **Option 2 – Connecting Municipal-owned field devices back to PennDOT Network** [PennDOT and Municipal Business Partners access the cabinet]
    - Conditions 1 and 2 permitted if a secure T-1 Network Connection can be established. Only permitted if this is the only connection throughout the municipality.
    - Condition 3 needs a PennDOT approved ISR Router to Connect back to the Commonwealth network.
    - Typically, all Field Devices need to be brought back to a Central Node.
    - PennDOT IT approved ISR Router to connect back to the Commonwealth Network.
    - Condition 1 and 2 Connect back through OA's Business Partner Network
    - No direct connection of field network to municipality's network. The municipality must use OA VPN to access field devices.

  - No direct connection or connection of individual field devices back to PennDOT's network.

- **Option 3 – Connecting Municipal-owned field devices sent back to the municipality and PennDOT** [PennDOT and Municipal Business Partners access the cabinet]
  - Condition 3(B) is only permitted.
  - Devices need to be brought back to a Central Municipal Location.
  - Design staff will work with PennDOT IT to determine the most appropriate ISR Router to connect back through OA's Business Partner Network.
  - No direct connection or connection of individual field devices back to PennDOT's network.

- **Option 4 – Other connections not outlined above.**
  - Preliminary coordination and discussion with PennDOT IT are required before finalizing an approach.

2 DESIGN PHASE

This section covers key items to be considered by the design consultant and PennDOT during the design of a PennDOT ITS project: Design Deliverables, Design Timeline, and Design Process.

2.1 ITS Design Deliverables

This section provides the project deliverables and stakeholder responsibilities during each stage of the ITS design process. It should be noted that some of these indicated deliverables may not be required on every ITS design project; however, this should be used as a starting point when developing the design scope and budget with PennDOT.

- **Table 2-1** provides general ITS project deliverables.
- **Table 2-2** provides deliverables specific to certain ITS devices.

Table 2-1: General PennDOT ITS Design Deliverables

Phase	Deliverables/Steps	Responsibility	Reviewer	Approval Agency
Scoping	Design Scope/Budget	Designer PennDOT PM	District ITS staff	District ITS staff Central Office FHWA
Systems Engineering Process	Systems Engineering documents ***See Appendix A for Examples***	Designer	District ITS staff Central Office	District ITS staff Central Office FHWA
	30% plans	Designer	District ITS staff	District ITS staff
60%/DFV Submission	Device Locations Staked/Finalized	Designer	District ITS staff	District ITS staff
	Communications/power identified		District ITS staff	District ITS staff
	Utilities identified		District ITS staff	District ITS staff
	Draft quantities and items identified		District ITS staff	District ITS staff
	Proprietary items identified		District ITS staff	Central Office
	Safety report completed		District ITS staff	Central Office
	Environmental clearance documents submitted	District ITS staff Designer to Support	District ITS staff	DEP
	Software modifications or procurements identified	Designer	District ITS staff, Central Office	District ITS staff Central Office
90%/FDOM Submission	Draft Special Provisions	Designer	District ITS staff	District ITS staff Central Office
	Draft Proprietary item letter		District ITS staff Central Office	Central Office FHWA
	Draft bid tabs, item list		District ITS staff	District ITS staff Central Office
	Power and communications details (equipment, wiring, routing, architecture, integration)		District ITS staff Central Office	District ITS staff Central Office
	Utility conflicts identified/resolved		District ITS staff	District ITS staff Central Office
	TS&L approved	Designer	District ITS staff	Central Office
	Draft cost estimate	Designer	District ITS staff	District ITS staff Central Office
	Software modifications or procurements finalized with vendor	Designer	District ITS staff Central Office	Central Office
100%/PS&E	All FDOM comments addressed and included in final bid package	Designer	District ITS staff Central Office	District ITS staff Central Office
	Software modification procurement incorporated into bid package	Designer	Central Office	Central Office
	Proprietary items approved		Central Office	Central Office FHWA
	Bid package uploaded to ECMS	District ITS staff CM	District ITS staff	Central Office
	All required forms, pre-bid schedules, etc. are completed and uploaded to ECMS as needed	Designer and District ITS staff CM	District ITS staff	Central Office

Table 2-2: Device Specific Design Deliverables

Device Type	Phase	Deliverables/Steps	Responsibility	Reviewer	Approval Agency
Travel Time Sensor	60%/DFV Submission	A Travel Time Memo that includes all the travel time links that will be required to post travel time messages onto the project DMS is developed. ***See Appendix B for Example***	Designer	District ITS staff	District ITS staff
	60%/DFV Submission	All potential links need to be evaluated to determine if they will work based on link lengths/spacing, etc.	Designer	District ITS staff Central Office	District ITS staff
	90%/FDOM Submission	Analysis needs to be coordinated to see if the approved travel time links from the travel time memo will be generated via real-time data from the installation of new TTS or if the existing INRIX data has a high enough confidence level that it could be used instead. **It should be during this phase that confirmation is received that all roadways needed to create these links are available in the PennDOT GIS database.**	Designer	District ITS staff Central Office	District ITS staff Central Office
	100%/PS&E	If TTS will be bid as an item on the project, there needs to be a special provision requiring the contractor to upgrade and integrate links into the BR server	Designer	District ITS staff Central Office	District ITS staff Central Office
DMS	60%/DFV Submission	A DMS message memo, which includes any travel time message and/or special messages (graphics, etc.), is developed to determined what will be posted on each sign in the project.	Designer	District ITS staff	District ITS staff Central Office
CCTV	In general, the design process of CCTVs follows all the steps listed above in Table 1 with no additional deliverables required.				

2.2 ITS Design Timeline

This section provides a typical timeline for each phase in the ITS design process and is intended to be used as a scheduling guide as all design schedules will vary based on the project. ITS design projects are often not standalone and are instead included as an ALSO plan set within a larger design project. Overall project schedules and deliverable dates should always be coordinated with the PennDOT Project Manager.

Design timelines for minor, moderate, and complex ITS projects are provided in **Table 2-3**. For the purposes of this guide, these categories are defined as follows:

- Minor Project
  - Consists of only a small number of device installations.
  - Device types have been deployed previously (e.g., CCTV, DMS, Vehicle Detection, HAR, RWIS).
  - Deviations from design standards are not anticipated.
  - Requires very little coordination between design disciplines and with other projects (i.e., may be a standalone ITS project).

- Moderate Project
  - Consists of 10 or more ITS device installations.
  - May require minor deviations from design standards.
  - Requires relatively straightforward communications and integration elements to be detailed.
  - May or may not be part of a moderately complex roadway or bridge project.

- Complex Project
  - Consists of a large number of ITS device installations.
  - Most likely includes new device types and/or systems.
  - Significant modifications to design standards are anticipated.
  - Requires communications network and TMC integration design elements.
  - Device deployments, integration, and testing may be phased and dependent on other aspects of the project.
  - May or may not be part of a large roadway or bridge project.
  - May or may not require substantial change to or creation of a new software module in ATMS.

Table 2-3: ITS Design Timeline

Phase	Minor	Moderate	Complex
Scoping	0-1 Months	1-2 Months	2-4 Months
Systems Engineering	1 Month	1-2 Months	3-6 Months
60% / DFV	3 Months	3-6 Months	3-12 Months
90% / FDOM	2 Months	2-3 Months	3-12 Months
100% PS&E	2 Months	2-3 Months	3-6 Months
TOTAL DESIGN TIME	8-9 Months	9-16+ Months*	14-40+ Months*

Phasing for ITS projects that are a component part of roadway and bridge projects may be subject to the submission schedule of the overall roadway/bridge design.

2.3 ITS Design Process

The key aspects of a PennDOT ITS design project are as follows:

- Project Scoping,
- Systems Engineering Process (30%),
- Design Field View (60%) Submission,
- Final Design (90%) Submission, and
- Final Plans, Specifications and Estimate (100%) Submission.

The figures below provide a flowchart of critical items that the design consultant should evaluate during the ITS design process.

- **Figure 2-1** provides a flowchart for a project with typical ITS system deployments.
- **Figure 2-2** provides a flowchart for a project with new ITS system deployments.
- **Figure 2-3** provides a flowchart for a project with ATMS modifications or enhancements.

Additional background information covering items in the flowchart can be found in subsequent sections of this guide. It should be noted that more than one flowchart may need to be referenced, depending on the systems included in a project. Each flowchart follows the same key milestones during the design process.

Figure 2-1: Design Process Flowchart for Project with Typical ITS Deployments

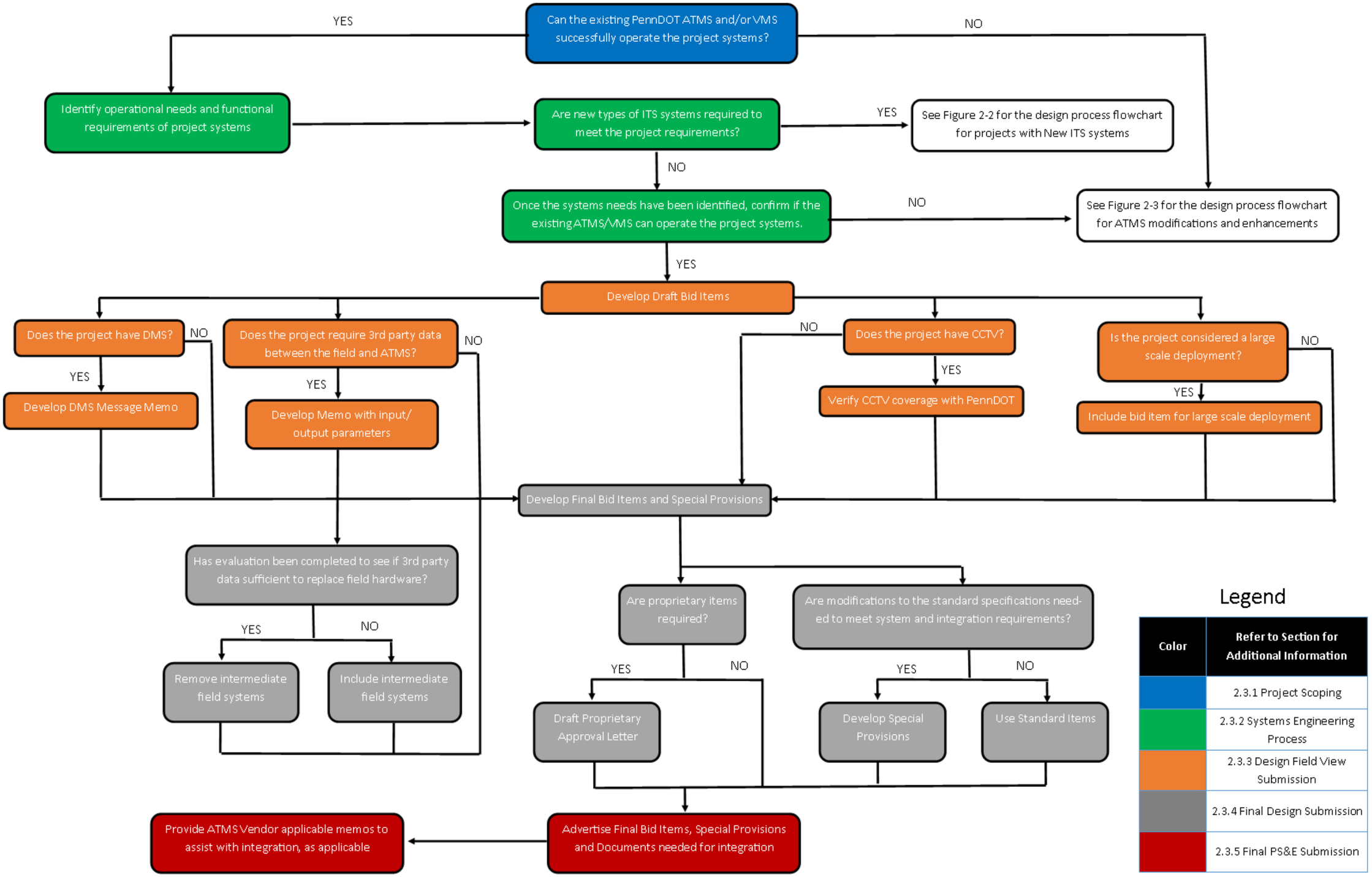


Figure 2-2: Design Process Flowchart for Project with New ITS System Deployments

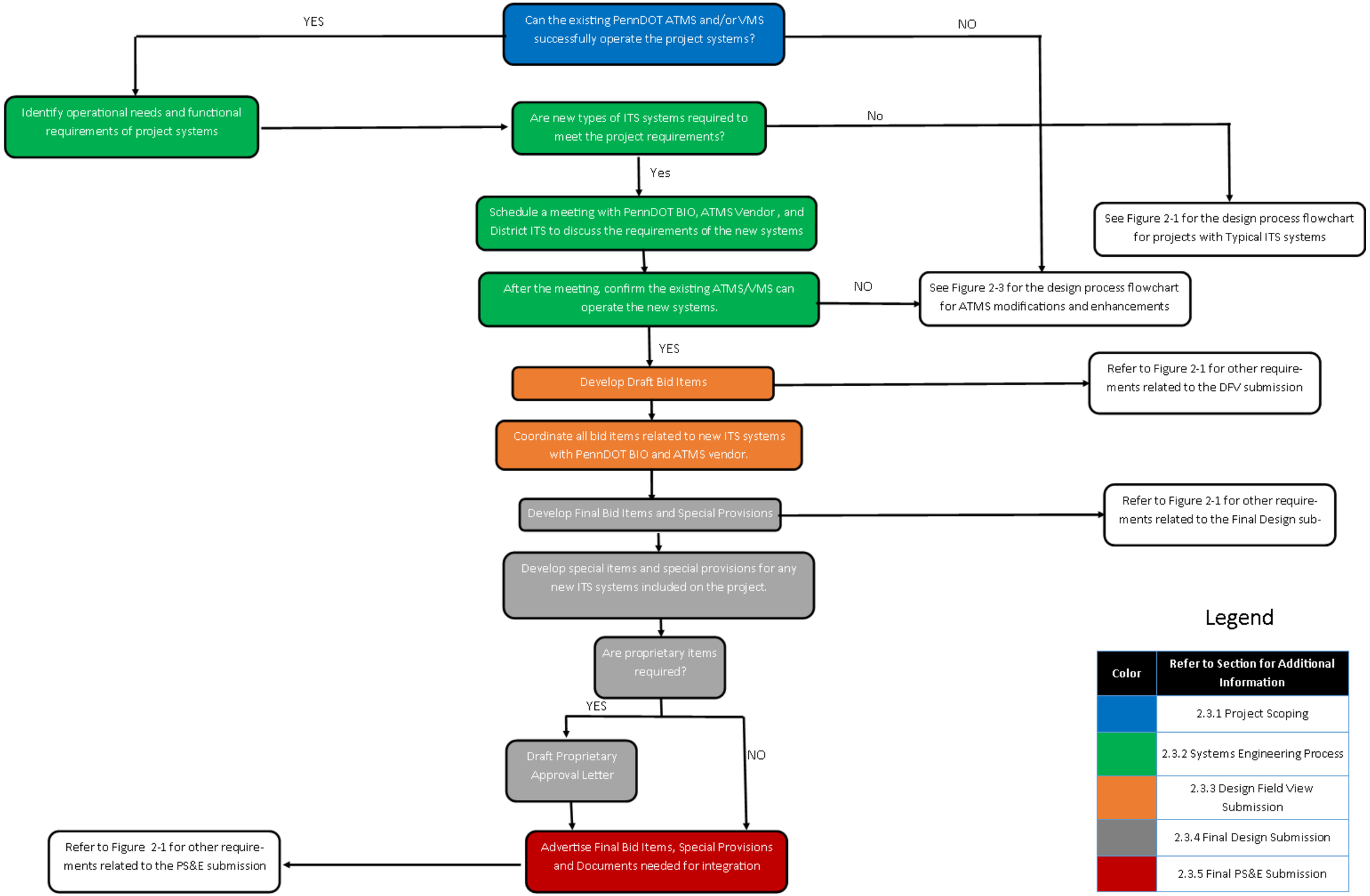
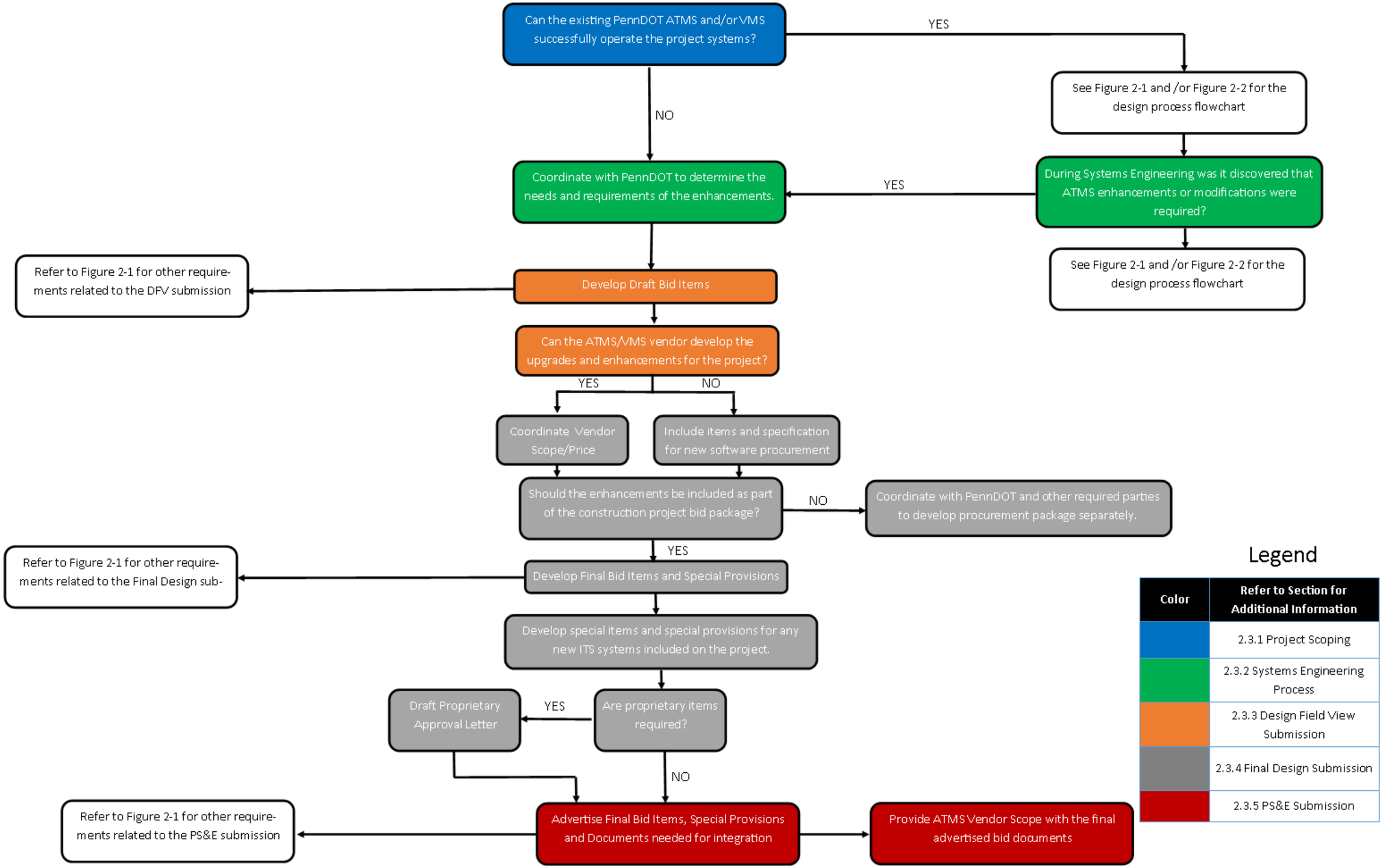


Figure 2-3: Design Process Flowchart for Project with ATMS Modifications/Enhancements



Color	Refer to Section for Additional Information
	2.3.1 Project Scoping
	2.3.2 Systems Engineering Process
	2.3.3 Design Field View Submission
	2.3.4 Final Design Submission
	2.3.5 PS&E Submission

2.3.1 Project Scoping

During initial design scoping between PennDOT and the design consultant, several items should be considered to ensure that all applicable integration coordination and required activities within the overall project are included:

- **ITS Systems**
  - Should be cross-referenced with capabilities and modules currently available in PennDOT's VMS and ATMS platform. Refer to **Figure 2-1** for design process flowchart.
  - If new types of ATMS systems are required, the additional effort to design and integrate these systems should be included in the design scope. Refer to **Figure 2-2** for design process flowchart.

- **ATMS Modifications/Enhancements**
  - Coordinate with PennDOT BOMO to determine if any aspects of the existing ATMS platform must be modified or enhanced as part of the project (e.g., deployment of new device/system, or need for new ATMS module/capability, such as an algorithm or operational feature.
  - Refer to **Figure 2-3** for design process flowchart.

2.3.2 Systems Engineering Process

All PennDOT ITS design projects should follow the Federal Highway Administration (FHWA) systems engineering process to effectively and efficiently process the specification, procurement, design, operation, and maintenance needs for applying advanced technologies to transportation. During this phase, the design team will determine all operational use cases and functional requirements for each system to be included in the project. The design team should evaluate all requirements to integrate the project systems based on the requirements of the regional ITS architecture.

- **Coordination** – The design consultant should coordinate with PennDOT District ITS staff to determine if a streamlined process can be utilized for the development of any systems engineering documents, such as the Concept of Operations (ConOps), the Systems Engineering Report (SER), or any functional or systems requirements documents. Often these documents include boiler plate language that may be able to be a reference rather than included in each document.

- **New ITS Systems** – If the systems engineering process determines that any new ITS systems must be deployed to meet PennDOT's operational or functional needs, the new systems should be coordinated with PennDOT District ITS staff, PennDOT BIO and the ATMS vendor to determine any additional requirements to be included in the design.

- **ATMS Modifications/Enhancements** – Once the systems engineering process has been completed for the project, the design team should again cross-reference the system requirements for the project against the current capabilities of PennDOT's ATMS platform. It is possible that the system engineering process will identify additional

modifications or enhancements needed for the ATMS system that were not evident during project scoping.

- If ATMS modifications/enhancements are required as a part of the project, these requirements should be developed during the system engineering process. In these instances, the design team should be coordinating with both PennDOT BIO and BOMO staff. This will be critical in the determination of the performance requirements needed to successful development and integration of the ATMS enhancements during the integration phase of the project.

2.3.3 Design Field View Submission

The Design Field View (DFV) phase of an ITS project is typically when the design team will begin to develop high-level bid items that will be included in the project. The bid items will vary depending on what systems are included in the design. Some the of the key integration items that should be considered during the DFV phase are described below:

- **3rd Party Data Systems** – If the ITS project includes a system that requires the ATMS to integrate directly with a 3rd party vendor to obtain the system data, a memo should be developed outlining the various inputs and outputs that will be required for ATMS integration. An example of this is the inclusion of Travel Time Sensors (TTS) such as Bluetooth Readers (BR) in a project, for which the design team should develop a travel time memo illustrating what travel time links will be required as a part of the project integration. These travel time links will eventually be integrated into the ATMS Travel Time Engine and used to post Travel Time Messages on PennDOT DMS.
    - A similar process to the TTS should be followed for any element where the ATMS will be receiving process data from a 3rd party vendor.
    - The input/output memo shall be provided to the ATMS vendor at the end of the design phase for use during the integration.

- **DMS** – If the ITS project includes DMS, the project team should coordinate with PennDOT to develop a DMS message memo during the DFV phase of the project. This memo will include the proposed messages to be displayed on the project DMS. If the proposed DMS message is to include any special messages, such as messages that include graphics or color capabilities, these items should be identified in the memo. This memo should be coordinated with PennDOT District ITS staff and PennDOT BOMO prior to being finalized. If the project DMS will be required to post special message formats, PennDOT BOMO will need to coordinate this with the ATMS vendor to confirm if any ATMS enhancements or modifications are required.
    - The DMS message memo should be provided to the ATMS vendor at the end of the project design for use during the integration.

- **CCTV** – If the ITS project includes CCTV, the design team should coordinate the optimal camera view with PennDOT District ITS and RTMC staff. This coordination will ensure the ITS design will allow for PennDOT view the desired traffic operations from the CCTV.

- **Large Scale Deployment** – During the DFV phase, the design team should coordinate with PennDOT BIO to determine if the project will be considered a "large-scale ITS

deployment." If the project falls into this classification, the design package will need to include a special integration item to accommodate the ATMS integration. If the project does not fall into this classification, then this additional item is not needed.

- **New Systems** – If the project includes new ITS systems, the design team should coordinate with PennDOT BIO and the ATMS vendor to determine what bid items are needed to procure the new systems as a part of the project. These bid items will likely require the development of special or modified items and system specific special provisions.

- **ATMS Modifications/Enhancements** – If the ITS project includes any software procurement or the modification/enhancement to the existing ATMS platform, these items should be finalized during the DFV phase. During this phase, the design team and PennDOT should make a final decision as to whether a new software is required to operate the project systems or if an update can be made to the existing ATMS.
    - If a new software system is desired, it needs to be determined whether that software will be procured and implemented under the construction contract or through a separate procurement package.
    - If the project will modify/enhance the existing ATMS, it needs to be determined whether the updates will be procured under the construction contract or through the existing statewide ATMS contract.

2.3.4 Final Design Submission

The Final Design phase of an ITS project is typically when the design team is developing the draft version of the final design. It is during this phase that the design team should finalize the project bid items and special provisions to be included for the ITS system and integration requirements. Some of the key items for consideration during this phase of the project are noted below.

- **3rd Party Data Systems** – If the ITS project will require ATMS to integrate with a 3rd party to obtain project data, the design team should complete an evaluation to determine if a direct 3rd party data source should be used instead of installing intermediate field systems. An example of this would be if the project is considering the installation of TTS. In this case, the design team should complete an evaluation to determine if INRIX data can be used instead of TTS. This final evaluation will determine the quality of INRIX data that is available along the project travel time segments and be used to make the final decision if TTS should be included in the final bid items.
    - If it is determined that TTS should be included as a project bid item, the project team will need to develop a special provision requiring the contractor to integrate the travel time links into the PennDOT server, which is separate from the ATMS Travel Time Engine.
    - A similar process to the TTS should be followed for any element where the ATMS will be received process data from a 3rd party device or server.

- **Special Provisions/Bid Items** – During the Final Design stage, the design team should review the existing PennDOT standard specifications (Publication 408 Section 1200) to determine if any modifications to these specifications is required based on the system

requirements. One of the key items that should be coordinated during this process is determining if the standard specifications for ITS Integration (Section 1202) covers all the information the ATMS vendor will need to integrate the project systems. The information required to integrate existing systems into PennDOT's ATMS are currently outlined in Section 1202 and the Task H spreadsheet template. As previously noted, the project may need a special item to support the integration of large-scale deployments.

- Another key item to be coordinated during this time is the item for ITS testing. The design team should be sure to coordinate with PennDOT to determine if any modified language needs to be added what is provided in Section 1201 to ensure all testing and operational support/maintenance is completed during the construction phase.
- During this phase of the project, the design team should review the system requirements with PennDOT and the ATMS vendor to determine if any additional information would be required for integration. If additional information would be needed, modified language would need to be developed as a special provision to be included in the integration bid item.

- **New Systems** – If the project includes new ITS systems, these systems will also need to be procured using special provisions and bid items. The final design submission should include these items in the submission. These items should be reviewed by PennDOT BIO and the ATMS vendor to ensure compliance into the ATMS platform.

- **ATMS Modifications/Enhancements** – Based on the previous coordination that has occurred during the design phase, the project team should have decided by the Final Design if a new software is required of if the existing ATMS can be modified.
  - If it is determined a new software will need to be procured under the construction project to operate the project systems, then the project team will develop a project bid item and special provision covering the requirements, identified in the systems engineering process, to procure the software.
  - If it is determined that the project will require a modification to the existing ATMS, then a scope should be developed by the ATMS vendor identifying how the vendor will complete the additional enhancements, and at what cost. This scope should be coordinated with PennDOT and based on the requirements identified during the systems engineering process. This scope should also outline the milestones and schedule that the enhancements will be completed.
  - If any ATMS modification or new software is to be procured for a project, the design team will need to coordinate the scope and budget for this bid item. The scope of these services should be used to determine if a pre-determined amount (PDA) item should be used for the bid. The vendor scope should include a detailed response to how the requirements are to be met as well as the milestones and schedules for all software design and development activities.

- **Proprietary Approval Letter** – If the project team determines that any proprietary systems will be required, the design team shall draft a proprietary approval letter to be

submitted to PennDOT during the design phase. A proprietary approval could be required as a part of any ITS project based on the system requirements.

2.3.5 Final Plans, Specifications & Estimate Submission

The Final Plans, Specifications & Estimate (PS&E) submission should include all final design items, specifications and documents necessary for the contractor to integrate the proposed systems during construction. Some of the key aspects that should be included are described below:

- **Special Provisions/Bid Items** – The final design document should include all required bid items and special provisions necessary for the contractor to integrate the systems into ATMS.

- **ATMS Modifications/Enhancements** – If a scope for the existing ATMS vendor was coordinated for a bid item, then the ATMS vendor scope should be included on ECMS in the bid documentation (less any information that is proprietary/needs to be redacted).

- **Proprietary Approval Letter** – If the project requires a proprietary approval, then the signed letter should be included on ECMS in the bid documentation.

3 INTEGRATION PHASE

This section discusses the important items to be coordinated between the ATMS vendor, the contractor, and the construction services team (PennDOT and consultants, as applicable) during the project integration phase.

3.1 ATMS Enhancement Schedule

This section provides a typical timeline required by the ATMS vendor to develop a modification/enhancement to the existing ATMS platform and is intended to be used as a scheduling guide as all construction schedules will vary based on the project. Overall project schedules and deliverable dates should be coordinated with the ATMS vendor and the project construction team.

Timelines for minor, moderate, and complex ATMS modifications/enhancements are provided in **Table 3-1**. For the purposes of this guide, these categories are defined as follows:

- Minor Project – Enhancements limited to adding a new vendor device into an existing module.
- Moderate Project – Minor modification of an existing module could be required based on updated requirements.
- Complex Project – Development of a new module or a substantial enhancement to an existing module.

Table 3-1: ATMS Modification/Enhancement Timeline

Phase	Minor*	Moderate*	Complex*
Submittal Review	3-5 Months	3-6 Months	6-9 Months
Detailed Software Design	N/A	0-3 Months	3-6 Months
Software Development	N/A	0-6 Months	3-12 Months
User Acceptance Testing	N/A	0-1 Month	1-2 Months
Systems Acceptance Testing	1 week -1 Month	1-2 Months	1-3 Months
Operational Testing/Support	5 Months	5-12 Months	12-30 Months

Timelines are not aggregate and may overlap. Overall construction duration may be a function of field installation.

3.2 Integration Phases

The key aspects during the integration phase for a PennDOT ITS project are as follows:

- Equipment Submittals,
- Integration Requirements and Kick-Off Meeting,
- Field Installation/Physical Construction,
- Final Integration, and
- System Testing.

The figures below provide a flowchart of critical items the construction team will encounter during the ITS integration process:

- **Figure 3-1** provides a flowchart for a project with typical ITS deployments.
- **Figure 3-2** provides a flowchart for a project with new ITS system deployments.
- **Figure 3-3** provides a flowchart for a project with ATMS modifications or enhancements.

It should be noted that more than one flowchart may need to be referenced depending on the systems that are included in a project. Each flowchart follows the same key milestones during the design process.

Figure 3-1: Integration Flowchart for Project with Typical ITS Deployments

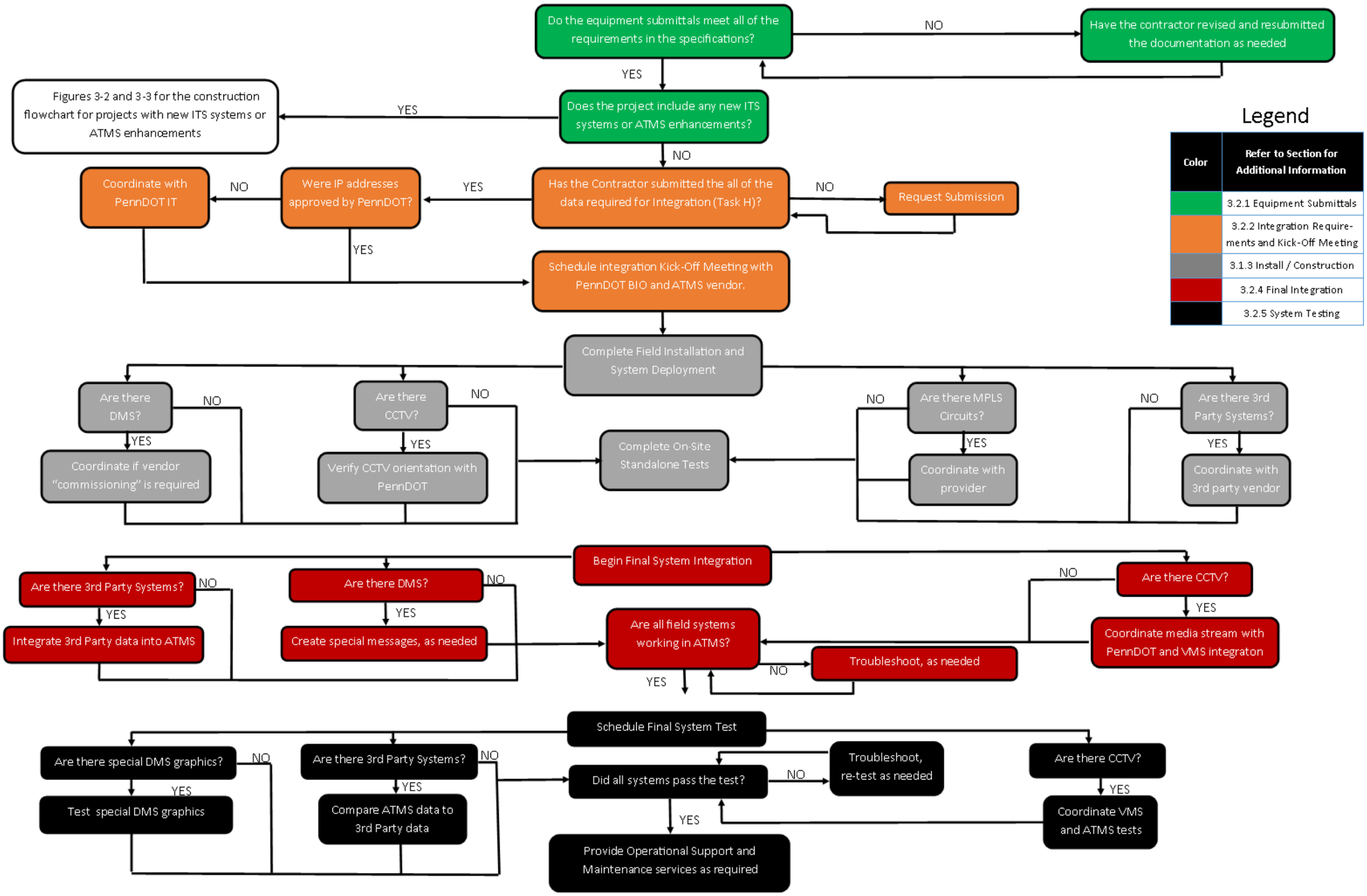


Figure 3-2: Integration Flowchart for Project with New ITS System Deployments

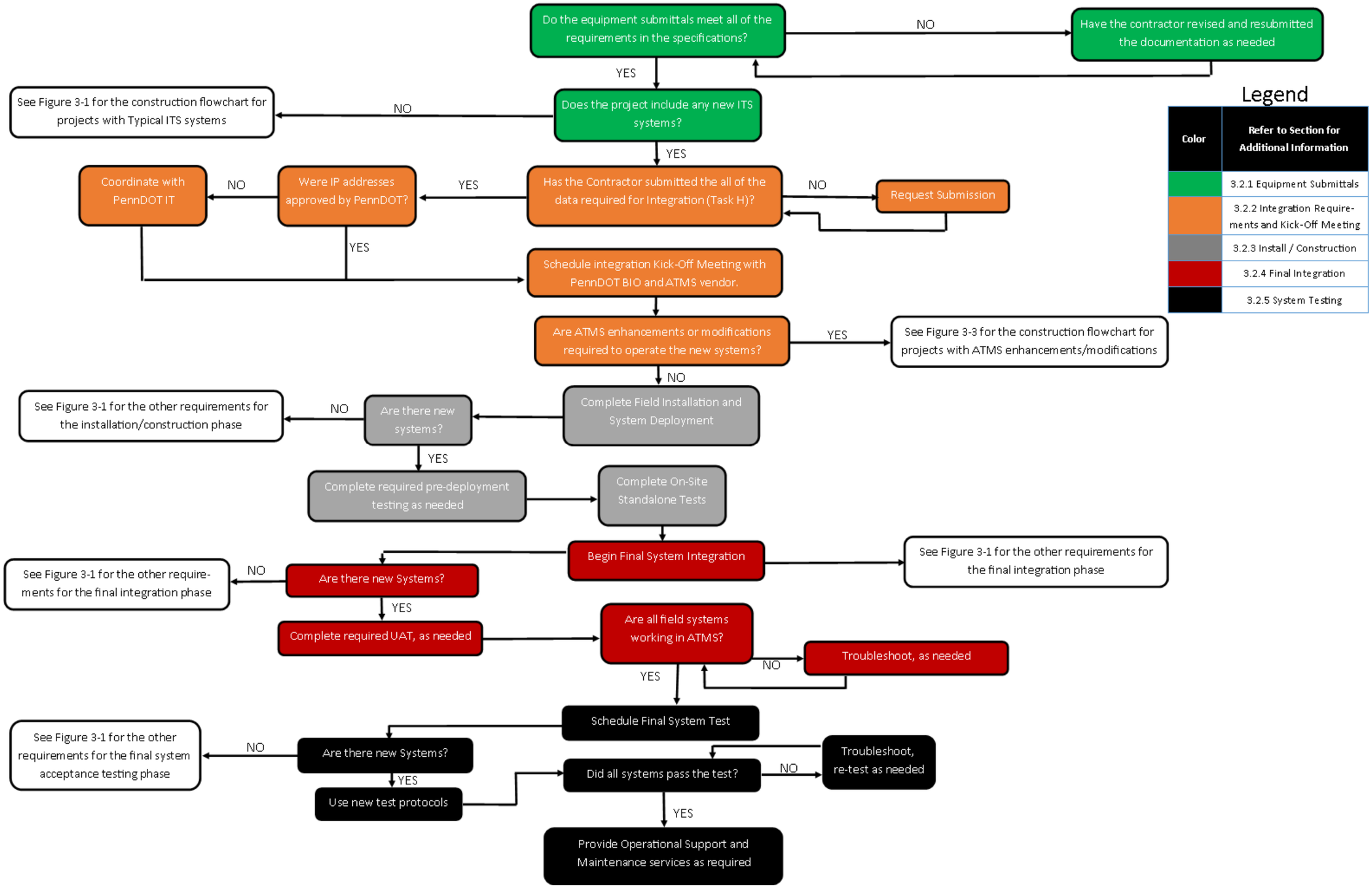
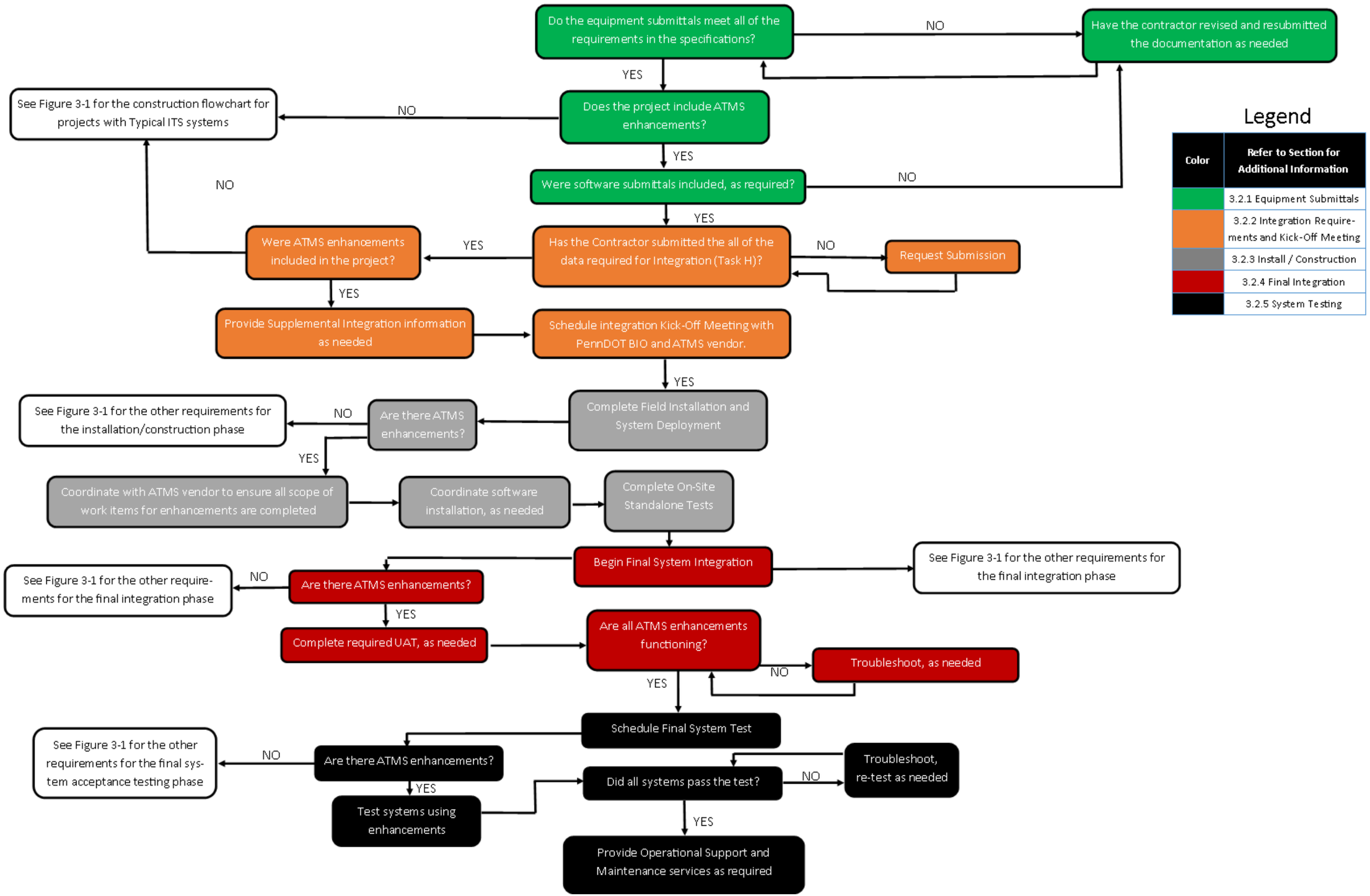


Figure 3-3: Integration Flowchart for Project with ATMS Modifications/Enhancements



3.2.1 Equipment Submittals

Prior to the physical construction of any systems taking place, the contractor is required to submit information of all the project's system equipment hardware and software for review and approval. These submittals will be reviewed against the requirements from the PennDOT standard specifications along with the project special provisions. Once the contractor submits this information, the construction services team should be sure to coordinate with PennDOT BIO, BOMO and the ATMS vendor to confirm the compatibility of the specific make and model of the equipment, as applicable. If the ATMS vendor has not previously integrated the specific manufacturer's equipment submitted by the contractor into the ATMS platform, the ATMS vendor may need to develop a new equipment configuration for the system. In these instances, the project team should give the ATMS vendor as much notice as possible in order to allow the vendor to develop the configuration. Completing this coordination as early as possible during project construction helps mitigate possible delays related to system integration later in the project.

Some specific items to consider during the equipment submittal phase are listed below.

- **ATMS Modifications/Enhancements –** If the project requires the procurement of any new software required to operate any project systems, all software design and integration submittals from the software vendor should be included as an equipment submittal. The construction services team will need to ensure that the software submitted by the contractor meets all the functional and performance requirements to successfully operate the project system(s).
    - If the project is modifying the existing ATMS platform, the construction services team should ensure that any equipment submittals required in the ATMS vendor's scope are provided for review and approval.

- **New Systems –** If the project is procuring any new types of systems that are not currently in use by PennDOT, the construction services team shall coordinate during the equipment submittals period to ensure the system is compatible with the system integration requirements. During this stage, the project team should also coordinate the submittal of any new testing protocols or pre-deployment testing requirements that may be needed for these systems.

3.2.2 Integration Requirements and Kick-Off Meeting

Once the equipment submittals for all the project system materials have been approved, the contractor shall provide all the required information needed to integrate each of the systems. The construction services team should coordinate with the contractor to have this information submitted through the project. The construction services team should share this information with PennDOT BIO and the ATMS vendor. This information is what the vendor and PennDOT BIO will utilize to integrate the project systems into the ATMS and VMS platforms. The information that the contractor is required to provide should follow the *Task H spreadsheet template*, which has previously been developed and approved by PennDOT BOMO. A copy of the *Task H spreadsheet template* has been provided as **Appendix C**.

Once the integration information has been submitted by the contractor, a mandatory Integration Kick-Off Meeting should be scheduled.

If additional information is required to integrate a system, the contractor should add this information to the template spreadsheet as a part of the submission. The information included in the submittal should meet the requirements outlined in PennDOT Publication 408 Section 1202 and any applicable project special provisions.

When the construction services team provides the integration information to the ATMS vendor, they should also include any project specific information that will be required to integrate and/or test the project system(s). This information could include the DMS message memo or Travel Time Link Memo.

Some additional information related to the integration requirements is provided below.

- **ATMS Modifications/Enhancements –** If the project requires the procurement of any new software required to operate any project systems, the construction services team should coordinate with the appropriate staff to determine what information is needed to integrate the project system(s). It is the role of the construction services team to ensure that this information is submitted by the contractor early in the construction phase to avoid potential delays during integration of the new software.
    - If the project is modifying the existing ATMS platform, the construction services team should be sure to have the contractor coordinate directly with the ATMS vendor to see if any additional information will be needed to integrate the project system(s) into the enhanced/modified functionality/modules.

- **IP Addressing –** The contractor should coordinate with PennDOT BIO to determine the IP address scheme to be utilized by the project systems.

3.2.3 Field Installation/Physical Construction

It is critical that the construction services team and the ATMS vendor coordinate throughout the construction phase of the system deployment. The construction services team should provide project and schedule updates to the ATMS vendor. This coordination will help mitigate potential delays that could occur when the project systems are ready to be integrated. It is during this phase that the project construction services team ensures that the project systems are deployed in accordance with the bid package/project design.

Several system specific items that should be coordinated during the construction phase are provided below.

- **MPLS Circuits -** If the project requires the use of leased circuits for any systems communication, it is important that this is coordinated during the construction phase of the project phase of the project. These leased services will need to be coordinated with the District PennDOT ITS staff as well as PennDOT Central Office. These services will be required to be coordinated and connected prior to the ATMS vendor being able to successfully integrate the project systems.

- **3rd Party Data Systems -** If a project is deploying a system that will require the ATMS vendor to integrate with a 3rd party, the construction services team and contractor will need to ensure that the 3rd party integration occurs prior once the equipment has been installed in the field. An example of this would be when a contractor is installing TTS. The TTS server integration must occur prior the ATMS vendor can successfully integrate any TTS units into the ATMS Travel Time Engine. The contractor shall coordinate directly with the TTS server vendor to provide whatever information is needed to create the project TTS links in the TTS server. The construction services team should make sure the TTS vendor has any required documentation, such as the Travel Time links memo, needed to complete the integration. The project team should be sure to have the ATMS vendor and the TTS server vendor coordinate with each other in order to have a successful system integration.

- **CCTV -** If the project is deploying CCTV systems, the construction services team should make sure there is coordination between the contractor and District ITS staff to ensure that the installation is completed to enable the proper viewing angle/coverage is provided.

- **DMS -** If the project is deploying DMS systems, the construction services team will verify if any work needs to be completed by the DMS vendor prior to scheduling the on-site standalone testing. Some vendors require a "commissioning" of the equipment to be completed prior to the DMS being ready for operational use.

- **New Systems-** If the project is deploying any new types of ITS systems, the constructions services team will verify if any pre-deployment tests that were required, such as the Factory Demonstration Test, have been completed. Typically, PennDOT does not require these pre-deployments test on equipment that is already installed within the District. However, when new systems are being deployed, these tests should be completed as required.

- **ATMS Modifications/Enhancements –** If the project requires the procurement of any new software required to operate any systems, the construction services team should coordinate with the contractor to have the software is installed on all required hardware prior to testing and integration. All software installation must be coordinated through PennDOT District IT and Central Office, as applicable and be in accordance with the approved vendor proposal/contract.
    - If the project is using the ATMS vendor to modify or enhance any aspects of the existing ATMS, the construction services team should monitor these modifications to ensure the ATMS vendor is following the enhancement scope and schedule. The construction services team should coordinate these items with PennDOT BOMO as needed.

3.2.4 Final Integration

After the contractor completes all the physical construction and on-site standalone testing for each of the ITS systems, the project team should coordinate with the ATMS vendor and

PennDOT BIO to allow them to begin the integration process. The ATMS vendor and PennDOT BIO will need all field communications to be established prior to starting the integration process. The ATMS vendor and PennDOT BIO typically require 4-6 weeks to complete all project integration work, but this timeline should be coordinated on a project by project basis. This integration work must be completed prior to the contractor being able to complete the final system testing. The construction services team should facilitate coordination between the contractor, ATMS vendor, PennDOT District ITS staff and PennDOT BIO to schedule the system testing date based on the ATMS integration.

Several system specific items that should be coordinated as a part of the system integration are provided below.

- **3rd Party Data Systems –** If the project is installing a system that requires 3rd party integration, the contractor is responsible for coordinating the integration of the system with the 3rd party vendor. The 3rd party vendor will establish the necessary inputs and outputs required for the ATMS vendor to directly pull any data needed to operate the system within the ATMS platform. It should be noted that often times the 3rd party vendor will need to monitor the input and output data from the project over a period of a few weeks and complete any necessary calibrations to ensure the accuracy of the data.
    - Once the 3rd party vendor indicates that the data has been calibrated, the ATMS vendor can begin to integrate the data into the ATMS platform.

- **CCTV –** If the project includes CCTV cameras, the project team will need to coordinate that each CCTV is integrated into PennDOT's Genetec VMS. This platform is separate from the ATMS integration and should be coordinated directly with PennDOT BIO.
    - As noted in the Field Installation/Physical Construction Section, if the project is also integrating the CCTV video feeds into the ATMS, then PennDOT BIO will need to create a CCTV media stream and provide it to the ATMS vendor. PennDOT typically needs one to two weeks to create a media stream, based on its current backlog. Once the CCTVs are ready for integration, the project team should request the ATMS vendor to request a ticket to PennDOT BIO to create the media stream.

- **DMS –** If the project includes DMS, the project team should coordinate with ATMS vendor to see if any travel time messages need to be created during final integration to support the final systems acceptance testing. The construction services team should also coordinate to see if any special graphics need to be provided to the ATMS vendor to support the integration effort.

- **New Systems –** If the project is integrating and new types of ITS systems, make sure all system documentation has been provided to the ATMS vendor to assist with integration. The ATMS vendor may need additional time to integrate new systems as it is likely that additional User Acceptance Testing (UAT) will need to be performed prior to the systems being ready for final acceptance testing.

- **ATMS Modifications/Enhancements –** Any new software or software enhancement will follow its own testing schedule (typically a factory demonstration test and user acceptance testing) prior to the final integration of all the devices. If possible, it would be best to perform user acceptance testing on live data/devices, so that needs to be coordinated with the construction contractor to see if any/which devices will be available per the schedule. It also may be required for the contractor to provide the software vendor with device equipment for their use in developing and configuring the software/enhancement.

3.2.5 System Acceptance Testing

Once the final integration has been completed, the final Systems Acceptance Testing can take place. The contractor should coordinate with PennDOT ITS staff and the ATMS vendor to schedule a system acceptance testing date. The project team should utilize the system acceptance testing protocols provided by the ATMS vendor to confirm the operational and performance requirements of each system using the ATMS platform. The project team should coordinate with PennDOT and the ATMS vendor to see what level of support will need to be provided (on-site, phone conference, not needed, etc.) by the ATMS vendor during the testing.

Once each system on the project has passed the acceptance tests, the construction services team should ensure the testing documentation is signed by the appropriate project personnel (contractor, PennDOT, consultant, ATMS vendor, etc.).

The construction services team should also coordinate with the contractor to ensure all operational support and maintenance requirements are followed once the system acceptance testing is completed.

Several system specific items that should be considered as a part of the system testing are provided below.

- **3rd Party Data Systems –** If the project will be testing data in ATMS that is coming from a 3rd party, the project team will need access to both the ATMS data and the 3rd party data during the testing. In order to test the 3rd party data, the project team will need to compare the 3rd party data to the data generated in ATMS. It should be noted that some of the ATMS modules and engines may be "smoothing" the data that it received from the 3rd party vendor based on how the data is being used in ATMS. Because of this data "smoothing" it is likely that the data from the 3rd party may not exactly match the data in ATMS. The project team should coordinate with the ATMS vendor to get an understanding on what an acceptable threshold is for the difference in ATMS and 3rd party data.

- **CCTV –** If the project includes CCTVs, the project team should coordinate with PennDOT District ITS staff to determine how the CCTV testing will be completed.
    - If PennDOT would like to test the CCTV video using the ATMS platform, the project team shall complete the test protocols within ATMS. It should be noted that the video feeds through ATMS will experience a lag based on communications with the ATMS servers in Harrisburg.

  - If PennDOT would like to test the CCTV video through the Genetec VMS, the project team shall verify that all the functionality outlined in the ATMS test procedures is working properly. It should be noted that everything outlined in the ATMS testing procedures can be verified through Genetec, but some of the language may not be applicable.
  - If PennDOT wants to test the CCTVs in both platforms, then the language outlined above should be utilized.

- **DMS –** If the project requires testing of any special DMS messages, such as graphics, then these messages should also be verified during the final acceptance test. The development of any special graphics should have been coordinated earlier in the construction phase when the project team provided the DMS message memo to the ATMS vendor.
  - If travel time messages are to be tested, then all travel time links should be configured and tested prior to testing the travel time messages.
  - When completing certain test steps, the project team should coordinate with the ATMS vendor to see if any steps are only applicable for certain manufacturer equipment. Potential examples of this include the pixel test step (test pixels vs test all pixels), lamp test, and color text test. It should be noted that the standard testing protocols are generic, so every step may not be applicable to the project systems.
- **New Systems –** If the project is procuring any new types of systems that are not currently in the PennDOT ATMS, new testing protocols will need to be used for the testing.

- **ATMS Modifications/Enhancements –** All systems acceptance testing should be conducted through the vendor software utilizing live devices and data. Following completion of the Systems Acceptance test, and if previously coordinated in the vendor scope of work, final acceptance testing, and/or any required performance testing of the software system will follow the completion of the systems acceptance testing.

4 CONCLUSION

The intent of this guide is to provide guidance on key items that should be considered during the design and integration phases of PennDOT ITS projects. This guide is based on current ITS integration practices and are meant to serve as a starting point for the design and construction teams on PennDOT ITS projects.

Each ITS project throughout the various PennDOT Districts presents varying scenarios that should be considered and coordinated through the design and construction phases. It is possible that certain needs related to ITS systems or functional requirements may not be covered in this guide.

APPENDIX A: SYSTEMS ENGINEERING REPORT EXAMPLES

1. Typical ITS Project – SR 0422, Section M1B
2. Complex ITS Project – I-76 ITS Enhancements

Typical ITS Project: SR 0422, Section M1B

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Presented to:

pennsylvania
DEPARTMENT OF TRANSPORTATION

Pennsylvania Department of Transportation Engineering District 6-0

Tender for:

SR 0422, Section M1B Systems Engineering Report

February 1, 2017
Updated October 16, 2020

Submitted by:
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2301 Chestnut Street
Philadelphia, PA 19103

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APPENDICES

APPENDIX A: SR 0422, SECTION M1B TRAVEL TIME WHITE PAPER

1.0 PROJECT OVERVIEW

This document is as an update to the previously approved Systems Engineering Report for SR 0422, Section M1B (dated February 2017) and includes ITS devices and infrastructure that have since been added.

The Pennsylvania Department of Transportation Engineering District 6-0 (District 6-0) plans to improve US Route 422 (SR 0422) between the Berks County Line and the Sanatoga Interchange in Chester and Montgomery Counties under a number of projects over the next several years. This seven-mile section of SR 0422 consists of two travel lanes in each direction, six interchanges, and numerous bridges. District 6-0 plans to replace all bridges, including six critical structurally deficient bridges located within the project limits; address deficient geometry to improve safety; reconstruct deteriorating pavement; improve interchanges; and lengthen acceleration and deceleration lanes to meet current design standards. Reconstruction of this portion of SR 0422 will be completed as part of seven construction contracts, three of which (Sections M1A, M2A, and M2C) are currently under construction or completed.

SR 0422, Section M1B involves the total reconstruction of approximately 1.7 miles of the expressway in Lower Pottsgrove Township from approximately 650 feet west of the Porter Road crossing to approximately 730 feet east of the Park Road crossing and includes two bridges carrying SR 0422 over Porter Road and Sanatoga Road and Creek. SR 0422 will be reconstructed with a 9-foot left shoulder, two 12-foot lanes, and a 12-foot right shoulder in each direction of travel. A concrete glare screen will be provided for physical separation between eastbound and westbound traffic. The expressway will be reconstructed on both existing and new alignments meeting current design standards for horizontal radii, shoulder widths, and vertical clearance.

ITS deployment includes the installation of twelve (12) Dynamic Message Signs (DMS) and thirty (30) Closed Circuit Television (CCTV) cameras located in Montgomery, Chester, and Berks Counties:

- SR 0422 between Hanover Street and SR 0363 – seven (7) DMS and fourteen (14) CCTV cameras
- SR 0422 (Benjamin Franklin Highway) in Berks County – one (1) DMS
- SR 0100 – two (2) DMS and two (2) CCTV cameras
- High Street / Ridge Pike – seven (7) CCTV cameras
- SR 0724 / SR 0023 – two (2) DMS and eight (8) CCTV cameras

Also included are the retrofit/upgrade of the following existing devices along SR 0422:

- D422E_01 and D422E_02, and
- CM-402, CM-403, CM-404, CM-405, CM-406, CM-407, CM-408, CM-409 and CM-410.

Also included are the installation of fiber optic cable along SR 0422 from Hanover Street to SR 0023, along SR 0724 from Bridge Street (SR 1039) to SR 0023, and along SR 0023 from Ferry Lane to SR 0252.

The addition of new ITS equipment and integration with District 6-0's Regional Traffic Management Center (RTMC) is a joint effort between PennDOT District 6-0, the Federal Highway Administration (FHWA), and the Delaware Valley Regional Planning Commission (DVRPC). The primary stakeholder for the implementation of the ITS equipment as well as RTMC integration will be PennDOT District 6-0.

Figure 1 provides an overview of the proposed ITS device locations.

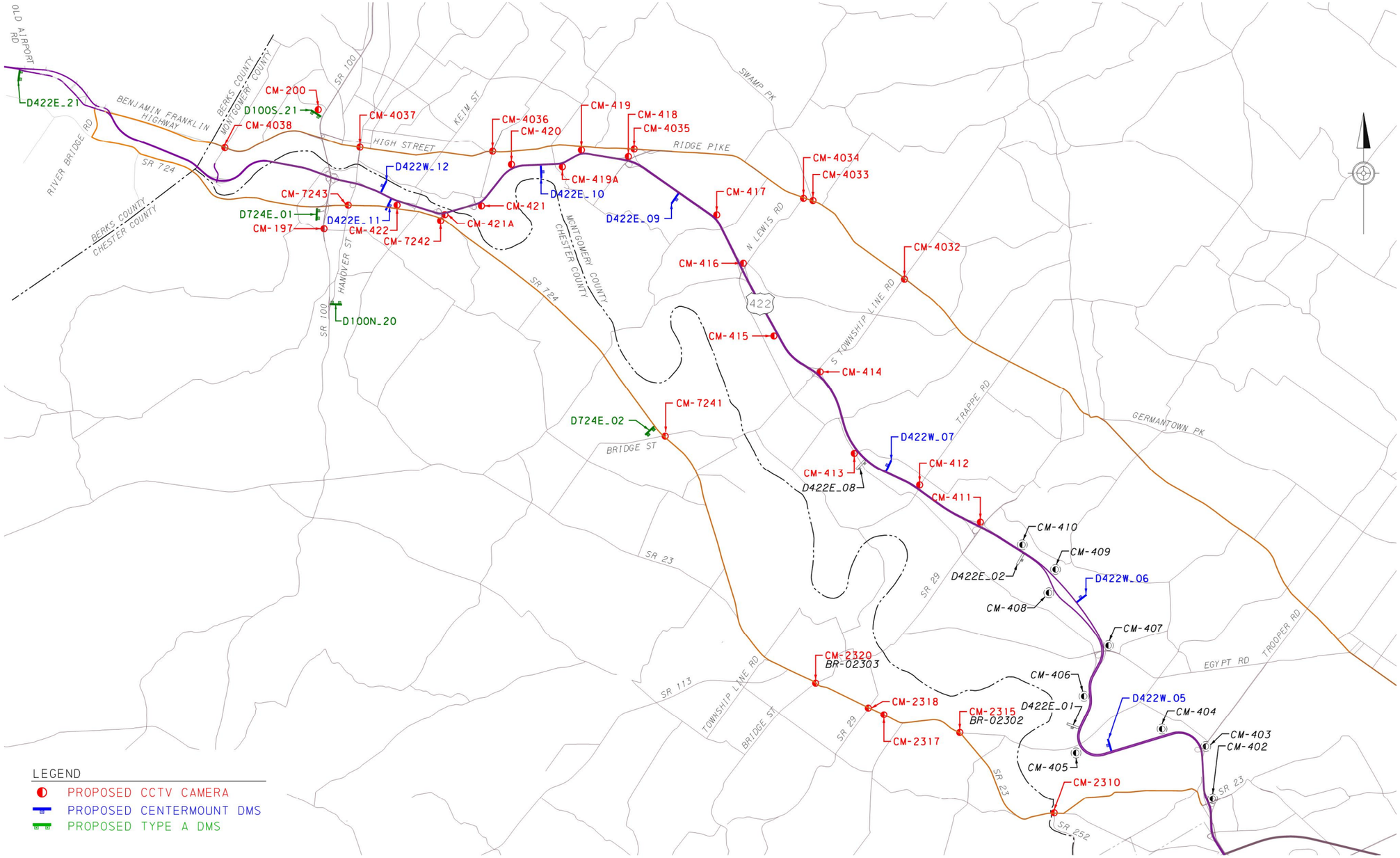

FIGURE 1: PROPOSED DEVICES OVERVIEW MAP

2.0 CONCEPT OF OPERATIONS

Systems engineering is a well-established project management methodology that provides a disciplined approach to building complex systems. It is a logical process that ensures that all activities in a project are conducted in a timely and economical manner. Systems engineering simplifies a project by merging management and technical activities within a single work process.

The International Council of Systems Engineering defines systems engineering as:

> *An interdisciplinary approach and means to enable the realization of successful systems. Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.*

Using a systems engineering approach, the project team can effectively and efficiently process the specification, procurement, design, operation, and maintenance requirements for applying advanced technologies to transportation. Thus, by guiding an intelligent transportation system (ITS) project through an orderly and comprehensive process, systems engineering provides an ideal approach for implementing cutting-edge transportation solutions.

The benefits of using a defined systems engineering approach include:

- Easier development and implementation of ITS project requirements;
- Combination of technical and management activities into a single work flow;
- Simpler project tracking and documentation via a defined process;
- More success meeting project schedule and budget targets;
- Systems with a verified functionality;
- A higher level of consistency between projects;
- Improved communications with stakeholders, management, and technical personnel; and
- Satisfaction of the U.S. DOT rule that requires the use of a systems engineering approach for all federally funded ITS projects.

The systems engineering process begins with defining a Concept of Operations (ConOps) and continues through the V-Diagram (see **Figure 2**) providing a traceable workflow.

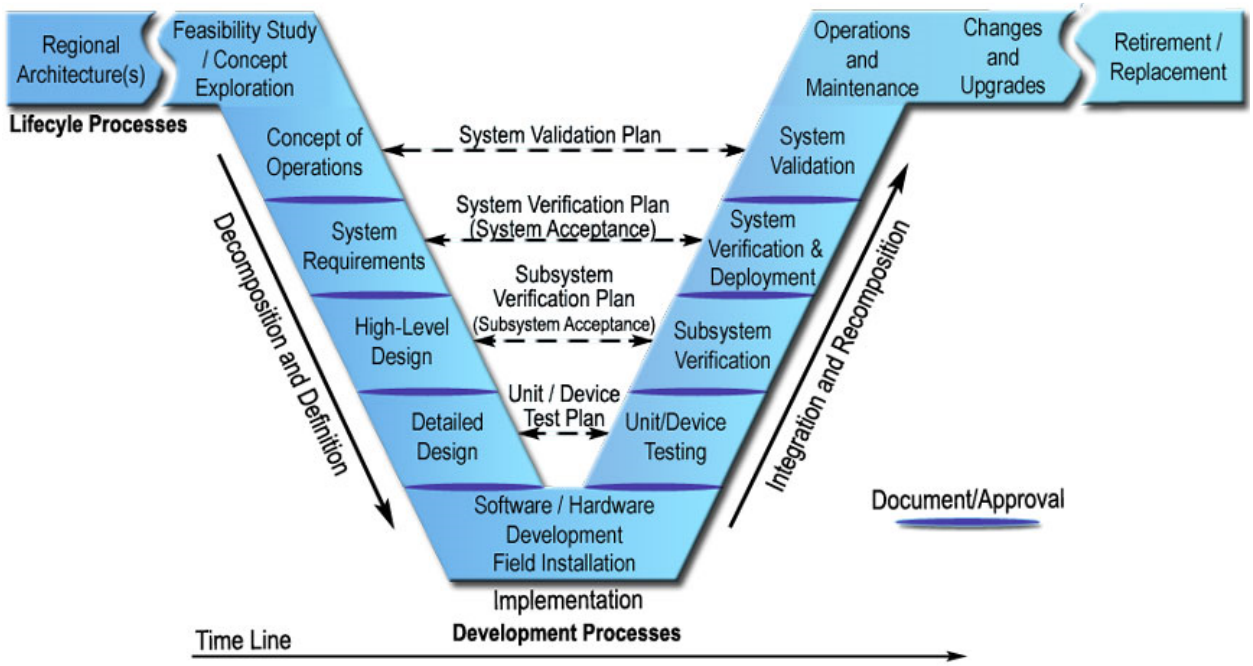

FIGURE 2: SYSTEMS ENGINEERING V-DIAGRAM

As shown in the V-Diagram, the systems engineering process begins with the study of the feasibility and conceptual overview of an ITS project. At this time, an initial project scope is developed based on the local and regional needs for the system. Continuing down the left side of the V-Diagram, the process progresses from the general definition of an initial concept and definition of system requirements through the detailed final design and ultimately arriving at the project construction phase. Progressing along the right side of the "V", components of the completed ITS system are tested and integrated into the region's overall ITS network. Finally, the completed system is validated to determine how well it is meeting the needs as defined during the development of the Concept of Operations. The lateral connections indicate the overlap between processes initiated in the early stages of the project with those that occur later. For example, the system verification and deployment phase of a project determines if and how well the system requirements are being met through system acceptance testing.

2.1 PURPOSE

The purpose of systems engineering is to define each of the steps along the V-Diagram prior to the project commencing, therefore all stakeholders are made aware of exactly what the requirements of the system are, and how the design, construction, and testing phases will meet those requirements throughout the project's lifecycle.

This document provides a technical overview for the implementation of ITS field devices and RTMC integration in King of Prussia. The ITS components recommended to be deployed are a logical continuation of the ITS planning efforts for the region. The ITS deployment and RTMC integration will meet the regional needs.

2.2 STAKEHOLDERS

PennDOT District 6-0 will be the owner and operator of the DMS and CCTV camera subsystems and is therefore the primary stakeholder for this project. Other stakeholders include:

- PennDOT Central Office
- Local Municipalities
- Motorists / Traveling Public
- Police / Emergency Responders
    - Pennsylvania State Police
    - Municipal Police
    - Montgomery County Emergency Operations Center
    - Chester County Emergency Operations Center

The FHWA, DVRPC, and Montgomery/Chester County Planning Commissions are also playing a large role in the development of the overall planning and reconstruction of the SR 0422 corridor but will not play a direct role in the operations of ITS devices.

2.3 REFERENCED DOCUMENTS

This section provides a list of documents related to the SR 0422 ITS additions. Related documents are not necessarily called out within the text of this plan. However, all related documents have been used in definition of the plan. By definition, some of these documents originate outside this project.

- *Developing and Using a Concept of Operation in Transportation Management Systems (December 2004)* – Federal Highway Administration.
- *Freeway Management and Operations Handbook (September 2003)* – Federal Highway Administration.
- *Regional ITS Architecture DVRPC Region V 1.0 (2001) and V 2.0 (DRAFT)* – Delaware Valley Regional Planning Commission.
- *Regional Operations Plan DVRPC/District 6-0 Region (July 2007)* – Pennsylvania Department of Transportation / Jacobs Edwards and Kelcey.
- *Publication 646: ITS Design Guide (2011)* – Pennsylvania Department of Transportation
- *Statewide ATMS Software Systems Manager – Statewide Functional Requirements (January 2006)* - Pennsylvania Department of Transportation / Edwards and Kelcey.
- *PennDOT Statewide ATMS Software Request for Proposals, Task H Integration Scope of Work*

2.4 USER-ORIENTED OPERATIONS DESCRIPTION

Perspective – PennDOT District 6-0

PennDOT District 6-0 currently controls ITS devices from its District Office in King of Prussia. The enhanced CCTV camera system coverage will provide PennDOT with surveillance capabilities of the SR 0422 Corridor during incidents and construction activities. The DMS system will provide PennDOT with the capability to provide real time traveler information to motorists traveling throughout corridor as well as provide RTMC staff with condition data through the work zone. CCTV and/or DMS along SR 0100, High Street / Ridge Pike, and SR 0724 / SR 0023 will also be included and will provide PennDOT with a view of vehicles as they

approach and exit the SR 0422 alternate routes as well as provide real time travel information to motorists.

Perspective – PennDOT Central Office
PennDOT Central Office will be involved in ATMS integration and securing travel time and incident detection data via a third-party data provider.

Perspective – Montgomery and Chester County Emergency Operations Centers
The CCTV cameras constructed as part of this project will support Montgomery/Chester County Emergency Operations in their response to incidents in the vicinity of the SR 0422 corridor. Both centers currently have video sharing connections to PennDOT. DMS also provide benefits in being able to provide enforcement related advisories, such as AMBER Alerts, and special event information.

Perspective – Municipalities
The ability to view CCTV video through the PA 511 website will assist local municipalities in deploying resources during incidents and periods of heavy congestion, particularly along SR 0422. The implementation of new DMS can also alert motorists to heavy congestion as well as advisory messages and special event information.

Perspective – Motorists / Traveling Public
Motorists will benefit from the newly installed ITS equipment consisting of DMS and CCTV cameras along SR 0422, SR 0100, High Street / Ridge Pike, and SR 0724 / SR 0023. These devices will provide motorists with condition information prior to entering the work zone as well as through PennDOT's 511 website.

2.5 OPERATIONAL NEEDS & REQUIREMENTS

The primary purpose of the SR 0422, Section M1B Corridor ITS deployment is to improve overall traffic management along SR 0422 between the Hanover Street and SR 0023 Interchanges through the deployment of ITS field devices and integration with the RTMC.

The following is a list of operational needs and requirements that will be addressed by the SR 0422, Section M1B Project.

District 6-0 Regional Traffic Management Center Integration (RTMC)
RTMC operations and central management software will have to be modified and/or upgraded to accommodate the installation of the new ITS devices along the SR 0422 corridor. This will include an upgrade to the OTN network management system, ATMS software, PA 511 interface, and installation/integration of additional communications equipment within the network room.

Closed Circuit Television (CCTV) Camera Subsystem
The CCTV camera subsystem should provide the capability to monitor traffic headway and to verify incidents relative to their operational location. Video equipment will be remotely controlled and generate standard video signals for routing to the District 6-0 RTMC.

More specifically, the video requirements are as follows:

- Provide high-resolution video to the RTMC;

- Allow management and control of CCTV cameras from the RTMC;
- Integrate into existing District 6-0 video management platform; and
- Provide capability for the RTMC to share video with the stakeholders.

Dynamic Message Sign (DMS) Subsystem

The DMS subsystem will provide motorists with traveler information including, but not limited to incident information, congestion, travel times, weather, special events, and AMBER alerts. They will be located in such a manner as to provide motorists with critical information in advance of major interchanges or decision points.

More specifically, the DMS requirements are as follows:

- Provide traveler information to motorists;
- Provide capability to display automated travel times;
- Provide AMBER alert messages; and
- Integrate with existing Statewide ATMS Software Platform.

Travel Time Reader Subsystem

The travel time subsystem will provide motorists with real-time travel times displayed on the DMS. The travel times will be calculated using third-party data. Data acquired from third parties will also provide coverage for the entire SR 0422 Corridor, thereby expanding the travel time data coverage well beyond the Section M1B project limits.

More specifically, the operational needs for the travel time subsystem are at a minimum:

- Collect and process vehicle travel time data from third-party data;
- Calculate "real-time" travel times based on data within the project limits;
- Store historical travel time data in a database;
- Provide capability to generate historical reports and graphs based on RTMC Operator defined measures of effectiveness including average speed and travel time; and
- Integrate into the travel time subsystem within the Statewide ATMS Software Platform. This includes providing visual condition information throughout the limits of the project.

Communications Subsystem

The communications network will serve both the current needs of the devices and future expansion of the TIMS system. The communications network will also provide for future expansion of the ITS device network as well as agency connections. The *PennDOT District 6-0 Fiber Optic Network Master Plan,* as well as the *ITS Design Guide* recommend fiber optic cable as the high-speed communications medium.

More specifically, the minimum operational needs for the communications subsystem are:

- Provide highly reliable high-speed data and video links between field devices / communications hubs and the RTMC to support data and high-resolution full motion video;
- Provide the ability for future high-speed connections to control centers of stakeholders;
- Provide compatibility with existing PennDOT communications infrastructure and protocols;
- Provide communications network redundancy where feasible;
- Provide capability of transmitting multiple networks; and
- Provide capability to integrate and connect with adjacent ITS deployments.

2.6 SYSTEM OVERVIEW

The SR 0422, Section M1B project includes a CCTV camera subsystem consisting of fourteen (14) new devices along SR 0422 between the Hanover Street and SR 0029 Interchanges. Each camera will be strategically located to provide complete visual coverage along SR 0422. The existing cameras along SR 0422 between the SR 0029 and SR 0023 Interchanges will be upgraded to IP format and all existing point-to-point connections converted to ethernet links so that the entire corridor will be part of an overall new fiber ring network. Additionally, the project includes the installation of two (2) cameras along SR 0100 in advance of the SR 0422 Corridor alternate routes, seven (7) cameras along the primary alternate route, and seven (7) cameras along the secondary alternate route.

Section M1B includes a DMS subsystem consisting of seven (7) centermount DMS that will provide information to motorists while en-route through the SR 0422 Corridor between the Hanover Street and SR 0363 Interchanges. The DMS will display travel times calculated from third-party data and will include travel time destinations outside of the project limits, such as SR 0100 for westbound traffic and SR 0029, SR 0363, and SR 0202 for eastbound traffic. Additionally, the project includes the installation of one (1) Type A DMS along SR 0422 (Benjamin Franklin Highway) in Berks County, two (2) Type A DMS along SR 0100, and two (2) Type A DMS along SR 0724 that will provide information to motorists as they approach and travel along the alternate routes.

Figure 3 illustrates a standard format for PennDOT DMS travel time messages.

```
AVG TRAVEL TIME
DEST 1    XX MI   XX MIN
DEST 2    XX MI   XX MIN
```

Or

```
AVG TRAVEL TIME
TO DESTINATION
XX MI      XX MIN
```

FIGURE 3: TRAVEL TIME STANDARD MESSAGING

2.7 OPERATIONAL AND SUPPORT ENVIRONMENT

Facilities

Primary control of the ITS systems will reside at the District 6-0 office building in King of Prussia, PA. All of the CCTV, DMS, and vehicle detection for travel time readers District-wide are controlled by the Statewide ATMS software platform. The RTMC is responsible for implementing real-time congestion management and incident management strategies essential to maximizing the operation and safety of the expressway system. The RTMC collects, coordinates, and disseminates traffic information to both incident management responders and motorists which is critical for incident management. Because of this, incidents can be cleared more effectively and travelers are provided with real time information to base their decisions on. The District 6-0 RTMC is staffed on a 24/7 basis. It is not anticipated that this project will require any additional RTMC components.

Equipment

As defined in the operational needs of the system, the following equipment and devices will be required to successfully deploy the SR 0422, Section M1B ITS system that meets project needs:

- Closed Circuit Television (CCTV) Cameras;
- Dynamic Message Signs (DMS);
- Travel Time Detection System (third-party data); and
- Communications Infrastructure (Device to RTMC, Center to Center; Fiber Optics, Ethernet equipment).

Hardware

All of the required hardware for the project will be identified through the design process. The deployed equipment will be consistent and compatible with existing PennDOT RTMC infrastructure in order to enhance the efficiency and ease of operations and maintenance activities. All equipment for travel time technology will be coordinated with the SR 0422 ITS system to streamline the integration of this data into the District's ATMS software.

Software

All ITS subsystems will be integrated into the existing ATMS and applicable Control Software for the District 6-0 RTMC. All required software modules have been developed as part of the implementation of the new ATMS, therefore integration effort for ITS field devices should be fairly limited, outside of driver development to integrate with new manufacturer's equipment. In the event that software modifications or new driver development will be required, then this will be covered under Task H Integration of the Statewide ATMS Software Contract. Task H includes the integration of devices not included in the original contract and has been included as an attachment to this document for reference.

Staffing

The District 6-0 RTMC is currently staffed on a 24/7 basis by three to four operators throughout the day, with capacity to accommodate additional operators if necessary. Two operators staff the RTMC between the hours of 12:00 AM and 4:00 AM. District 6-0 is currently in the process of expanding the RTMC in order to accommodate more staff and operator functions. It is not anticipated that any element of this project will require the hiring or training of additional staff.

3.0 FUNCTIONAL REQUIREMENTS

The Functional Requirements are descriptions of what the system must do to address needs, provide a service, and/or facilitate a stakeholder responsibility. A Functional Requirement is characterized by naming a system, the stakeholder, and presenting a list of "shall" statements that constitute the functions to be provided by the system. The Functional Requirements define how the needs of the stakeholders involved in the Project will be met. They are designed to meet the Goals and Objectives stated in the ConOps (Section 2.0 of this report). The Functional Requirements are categorized by each stakeholder and the systems that impact the respective stakeholder.

According to the FHWA publication *Developing Functional Requirements for ITS Projects*, an effective functional requirement should have the following characteristics:

Necessary – All requirements must trace to at least one need.
Concise – Stated in language that is easy to read.
Attainable – A realistic capability that can be implemented for the available money, resources and time.
Complete – All needs must be reflected by the requirements and not force the reader to look at additional text to know what the requirement means.
Consistent – Does not contradict other stated requirements nor is it contradicted by other requirements.
Unambiguous – Open to only one interpretation.
Verifiable – Must be able to determine the requirement has been met through one of four possible methods: inspection, analysis, demonstration or test.

Primary Stakeholders

PennDOT District 6-0

System: *CCTV System*
This system shall:

- Provide full surveillance coverage along the SR 0422 Corridor within the project limits;
- Provide limited surveillance coverage along SR 0100 in the areas of the SR 0422 Corridor alternate routes as well as along the primary and secondary alternate routes;
- Allow full device control (pan, tilt and zoom) from the District 6-0 RTMC;
- Support incident detection, verification, and response activities;
- Provide capability to restrict any and all device management functions with District 6-0 or other stakeholders;
- Provide capability to share any and all device management functions within District 6-0 or to other stakeholders;
- Report system status to RTMC operators; and
- Report system or individual device failures through alarms to RTMC operators.

System: *DMS System*
This system shall:

- Provide motorists with traveler information to assist in making trip decisions;
- Display alternate traffic route information during road closures;

- Display advisory messages, including AMBER alerts;
- Display travel time messages;
- Provide capability to share or restrict any and all device management functions with PennDOT 6-0 or other stakeholders;
- Report system status to RTMC operators; and
- Report system or individual device failures through alarms to RTMC operators.

System: *Travel Time System*
This system shall:

- Collect and process vehicle times from third-party data;
- Calculate real-time travel times;
- Provide the ability to integrate real-time travel times into the existing ATMS software;
- Provide the ability to match vehicle pairs to existing travel time readers on the SR 0422 Corridor in the King of Prussia area;
- Provide the ability to utilize third-party data to generate travel times and post on DMS;
- Provide the ability to store historical traffic data including space mean speed and travel time within PennDOT's ATMS software platform;
- Provide capability to share or restrict any and all device management functions with PennDOT 6-0 or other stakeholders;
- Report system status to RTMC operators; and
- Report system or individual device failures through alarms to RTMC operators.

System: *Communications System*
This system shall:

- Provide high-speed communications between all field devices and the RTMC;
- Provide capability for high-speed center-to-center communications between District 6-0 and project stakeholders in the future; and
- Provide for opportunities to expand and add additional ITS devices as new projects come under construction.

Secondary Stakeholders

Local Municipalities/Police

System: *CCTV System*
This system shall:

- Provide the ability to view CCTV camera images through the PA 511 website.

System: *DMS System*
This system shall:

- Provide AMBER Alert Messages through coordination with State Police and District 6-0 RTMC Operators.

System: *Communications System*
This system shall:

- Provide capability for future high-speed center-to-center communications between PennDOT 6-0 and municipalities; and
- Provide for capability of two-way communications between District 6-0 and project stakeholders to facilitate coordinated incident response.

Motorists / Traveling Public

System: *DMS System*
This system shall:

- Provide motorists with traveler information to assist in making trip decisions;
- Provide travel time information;
- Provide work zone information during construction activities;
- Display alternate traffic route information during road closures; and
- Display advisory messages including AMBER Alerts.

System: *Travel Time System*
This system shall:

- Provide motorists with real time travel time on DMS to assist in making trip decisions.

State Police / Emergency Responders

System: *CCTV System*
This system shall:

- Provide the capability to view District 6-0 video feeds through the PA 511 webpage in order to better coordinate emergency response; and
- Provide the capability for future direct sharing of video.

System: *DMS System*
This system shall:

- Provide AMBER Alert Messages through coordination with police.

4.0 PROPOSED ITS DEVICE LOCATIONS AND JUSTIFICATION

ITS device locations were selected to best provide the most operational functionality, while remaining within the permitting limits of the overall reconstruction project.

4.1 CCTV CAMERA LOCATIONS ALONG SR 0422

CCTV cameras are an essential element of any ITS system. They are used for Incident Detection and Incident Verification. CCTV cameras can help in early detection of an incident and reduce the response time of emergency responders. Also, incidents reported from other sources can be easily verified using the CCTV cameras from the control center. The status of the incident and also the resulting backup traffic can be monitored using the cameras. The RTMC operators can better customize their responses with continuous information about the developing scenario from the CCTV cameras.

CCTV cameras can also be used to monitor recurrent traffic congestion along expressways as well as on arterial roadways. Sections of roadway with lower speeds and higher lane densities can easily be detected. Weather conditions and road surface conditions such as snow, fog, ice, water, and flooding can also be monitored by RTMC personnel utilizing the cameras.

The images from CCTV cameras can also provide valuable information to travelers regarding traffic and weather conditions. Access to these images via the internet can greatly increase the safety and reduce the travel time of travelers by helping them in making more knowledgeable decisions about their trips. These images can also be utilized by other transportation and emergency response agencies to more effectively monitor and respond to incidents on the region's roadways.

The CCTV locations satisfy the requirements for comprehensive coverage by critical portions of the roadways visible, particular at major merge points and intersections where congestion is most likely to occur. These locations provide viewing of activity along adjacent streets. Camera locations have also been selected to minimize obstruction resulting from large guide sign displays, tree lines, and views around curves.

Table 1 lists the proposed camera locations along SR 0422. The locations were reviewed with District 6-0 RTMC staff during field views on September 14, 2016 and June 14, 2018.

Camera	Location
CM-422	SR 0422 west of Keim Street
CM-421A	SR 0422 at SR 0724 Interchange
CM-421	SR 0422 near Armand Hammer Boulevard
CM-420	SR 0422 west of Pleasantview Road
CM-419A	SR 0422 east of Pleasantview Road
CM-419	SR 0422 west of Park Road
CM-418	SR 0422 at Evergreen Road
CM-417	SR 0422 west of Limerick Center Road
CM-416	SR 0422 at Lewis Road

CM-415	SR 0422 at Country Club Road
CM-414	SR 0422 at Township Line Road
CM-413	SR 0422 at Mingo Road
CM-412	SR 0422 at Trappe Road
CM-411	SR 0422 at SR 0029

TABLE 1: PROPOSED CCTV CAMERAS ALONG SR 0422

CM-422

Location: CM-422 is proposed to be located adjacent to the SR 0422 EB lanes approximately 1,800 feet west of the Keim Street overpass and near the PI of the tangents for the horizontal curve.
Field of View: CM-422 will be located to provide a field of view matching those of CM-423 (proposed under SR 0422, Section M2C) to the west and CM-421A to the east.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the temporary aerial 24-strand fiber optic trunk being installed as part of this project. Electric power is available along Hanover Street.

CM-421A

Location: CM-421A is proposed to be located adjacent to the SR 0422 EB lanes at the PA 724 Interchange and near the PI of the tangents for the horizontal curve.
Field of View: CM-421A will be located to provide a field of view matching those of CM-422 to the west and CM-421 to the east.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along PA 724.

CM-421

Location: CM-421 is proposed to be located adjacent to the SR 0422 EB lanes just west of the Armand Hammer Boulevard overpass and near the PI of the tangents for the horizontal curve.
Field of View: CM-421 will be located to provide a field of view matching those of CM-421A to the west and CM-420 to the east.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Armand Hammer Boulevard.

CM-420

Location: CM-420 is proposed to be located adjacent to the SR 0422 WB lanes approximately 875 feet west of the Pleasantview Road overpass and near the PI of the tangents for the horizontal curve.
Field of View: CM-420 will be located to provide a field of view matching those of CM-421 to the west and CM-419A to the east.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Porter Road.

CM-419A

Location: CM-419A is proposed to be located adjacent to the SR 0422 EB lanes approximately 600 feet east of the Pleasantview Road overpass and near the PI of the tangents for the horizontal curve.

Field of View: CM-419A will be located to provide a field of view matching those of CM-420 to the west and CM-419 to the east.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Pleasantview Road.

CM-419
Location: CM-419 is proposed to be located adjacent to the SR 0422 WB lanes approximately 2,400 feet west of the Park Road overpass and near the PI of the tangents for the horizontal curve.
Field of View: CM-419 will be located to provide a field of view matching those of CM-419A to the west and CM-418 to the east.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Park Road.

CM-418
Location: CM-418 is proposed to be located in the NW quadrant of the Evergreen Road / Old Township Line Road Interchange.
Field of View: CM-418 will be located to provide a field of view matching those of CM-419 to the west and CM-417 to the east.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Evergreen Road / Old Township Line Road.

CM-417
Location: CM-417 is proposed to be located adjacent to the SR 0422 WB lanes approximately 850’ west of Limerick Center Road and near the PI of the tangents for the horizontal curve.
Field of View: CM-417 will be located to provide a field of view matching those of CM-418 to the west and CM-416 to the east.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Limerick Center Road.

CM-416
Location: CM-416 is proposed to be located in the NW quadrant of the Lewis Road Interchange.
Field of View: CM-416 will be located to provide a field of view matching those of CM-417 to the west and CM-415 to the east.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Lewis Road.

CM-415
Location: CM-415 is proposed to be located adjacent to the SR 0422 EB lanes at Country Club Road.
Field of View: CM-415 will be located to provide a field of view matching those of CM-416 to the west and CM-414 to the east.

Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Country Club Road.

CM-414
Location: CM-414 is proposed to be located in the NE quadrant of the Township Line Road Interchange.
Field of View: CM-414 will be located to provide a field of view matching those of CM-415 to the west and CM-413 to the east.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Township Line Road.

CM-413
Location: CM-413 is proposed to be located adjacent to the SR 0422 EB lanes at Mingo Road.
Field of View: CM-413 will be located to provide a field of view matching those of CM-414 to the west and CM-412 to the east.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Mingo Road.

CM-412
Location: CM-412 is proposed to be located adjacent to the SR 0422 WB lanes at Trappe Road
Field of View: CM-412 will be located to provide a field of view matching those of CM-413 to the west and CM-411 to the east.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Trappe Road.

CM-411
Location: CM-411 is proposed to be located in the NW quadrant of the SR 0029 Interchange.
Field of View: CM-411 will be located to provide a field of view matching those of CM-412 to the west and CM-410 (existing CCTV) to the east.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along SR 0029.

4.2 DMS LOCATIONS ALONG SR 0422

DMS provide a valuable means of communicating traveler information to motorists while traveling. They allow operators in the RTMC to convey information to motorists related to congestion, incidents, AMBER alerts, weather, and road closures. DMS are usually located in advance of major interchanges. DMS can also be paired with a travel time detection system to post travel times to various locations and assist motorists in planning their routes of travel. DMS placed on diversion routes assist travelers in planning an appropriate alternate route as well as notifying them where it is acceptable to re-enter the roadway. The DMS in District 6-0 utilize a combination of fiber optic cable and dial-up telephone lines to communicate with the RTMC.

DMS locations are coordinated with the placement of major route guidance signs to remain compliant with FHWA, PennDOT, and MUTCD sign placement standards. The requirements for sign visibility will assume 15-degree cone of vision to the perpendicular axis to the sign for a distance of 600 to 1,000 feet from the sign. The selection of locations for DMS along SR 0422 was driven by the information needs of motorists traveling eastbound. As the primary function of these DMS is to provide condition information (mostly travel time) and detour routing to diverted drivers, DMS were located in such a way as to ensure that information was relayed to travelers in advance of critical decision points along the route. This typically led to DMS being located in advance of major intersections and decision points.

In continuing with more recent DMS installation within District 6-0, the ITS design will incorporate full-matrix, full-color DMS in order to provide the most functional system and limit the amount of text drivers are required to process.

Table 2 lists the proposed DMS locations along SR 0422. The locations were reviewed with District 6-0 RTMC staff during field views on September 14, 2016 and June 14, 2018.

DMS	Location
D422E_21	SR 0422 west of Old Airport Road (Berks County)
D422W_12	SR 0422 east of Hanover Street
D422E_11	SR 0422 west of Keim Street
D422E_10	SR 0422 west of Pleasantview Road
D422E_09	SR 0422 west of Airport Road
D422W_07	SR 0422 east of Old State Road
D422W_06	SR 0422 west of Upper Indian Head Road
D422W_05	SR 0422 east of Pawlings Road

TABLE 2: PROPOSED DMS ALONG SR 0422

D422E_21

Location: D422E_21 is Type A DMS proposed to be located adjacent to the SR 0422 EB lanes approximately 500 feet west of Old Airport Road. This location was reviewed with RTMC staff during a field view on February 18, 2015 for SR 0422, Section M2C but was subsequently removed from that project. It is proposed to be included in Section M1B, as it serves to provide eastbound motorists with information well in advance of the River Bridge Road intersection. In the event of an incident along SR 0422 between Douglassville and SR 0100, motorists can either continue straight at this intersection to access the primary alternate route or turn right to access the secondary alternate route.

Field of View: Eastbound traffic on SR 0422 will have approximately 1,200 feet of tangent sight distance (14.8 seconds at 55 mph) to the DMS.

Communication and Power Sources: Communication will be via cellular modem. The intent is to replace this with fiber in the future, as there are plans to extend fiber to connect the existing District 6-0 ITS devices along SR 0422 in Berks County. Electric power is available along SR 0422 EB at the site.

D422W_12

Location: **D422W_12** is a centermount DMS proposed to be located adjacent to the SR 0422 WB lanes approximately 2,100 feet east of Hanover Street.

Field of View: Westbound traffic on SR 0422 will have approximately 950 feet of tangent sight distance (11.8 seconds at 55 mph) to the DMS.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the temporary aerial 24-strand fiber optic trunk being installed as part of this project. Electric power is available along Hanover Street.

D422E_11
Location: D422E_11 is a centermount DMS proposed to be located adjacent to the SR 0422 EB lanes approximately 2,100 feet west of Keim Street.
Field of View: Eastbound traffic on SR 0422 will have approximately 1,080 feet of tangent sight distance (13.4 seconds at 55 mph) to the DMS.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the temporary aerial 24-strand fiber optic trunk being installed as part of this project. Electric power is available along Hanover Street.

D422E_10
Location: D422E_10 is a centermount DMS proposed to be located adjacent to the SR 0422 EB lanes approximately 1,200 feet west of Pleasantview Road.
Field of View: Eastbound traffic on SR 0422 will have approximately 1,250 feet of tangent sight distance (15.5 seconds at 55 mph) to the DMS.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Pleasantview Road.

D422E_09
Location: D422E_09 is a centermount DMS proposed to be located adjacent to the SR 0422 EB lanes approximately 2,000 feet west of Airport Road.
Field of View: Eastbound traffic on SR 0422 will have approximately 3,000 feet of tangent sight distance (37.2 seconds at 55 mph) to the DMS.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Possum Hollow Road.

D422W_07
Location: D422W_07 is a centermount DMS proposed to be located adjacent to the SR 0422 WB lanes approximately 300 feet east of Old State Road.
Field of View: Westbound traffic on SR 0422 will have approximately 1,400 feet of tangent sight distance (17.4 seconds at 55 mph) to the DMS.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Old State Road Road.

D422W_06
Location: D422W_06 is a centermount DMS proposed to be located adjacent to the SR 0422 WB lanes approximately 950 feet west of Upper Indian Head Road.

Field of View: Westbound traffic on SR 0422 will have approximately 2,000 feet of tangent sight distance (24.8 seconds at 55 mph) to the DMS.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Cider Mill Road.

D422W_05
Location: D422W_05 is a centermount DMS proposed to be located adjacent to the SR 0422 WB lanes approximately 2,900 feet east of Pawlings Road.
Field of View: Westbound traffic on SR 0422 will have approximately 4,500 feet of tangent sight distance (55.8 seconds at 55 mph) to the DMS.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the 144-strand fiber optic trunk being installed as part of this project. Electric power is available along Pawlings Road.

4.3 TRAVEL TIME LOCATIONS

There are no Bluetooth reader locations proposed for this subsystem. Recently, District 6-0 was able to display travel time messages on the existing DMS along SR 0422 as well as those along the adjacent arterials (installed under SR 0422, Section SRB) utilizing only third-party data from INRIX. Based on this, it is proposed that the travel time subsystem for the SR 0422 limited access mainline as well as its alternate routes utilize INRIX data, which will be available through an existing PennDOT agreement with the provider. The existing travel time engine will be configured to receive additional data to compute travel times.

All DMS locations, both existing and proposed, along SR 0422 and the surrounding arterials have been reviewed and travel time messages developed for each. The messages have been coordinated to ensure that the message formats of existing and proposed DMS are consistent. In some cases, revisions to existing PennDOT messages are suggested in order to retain format consistency. More specific information concerning the proposed travel time system may be found in the *SR 0422, Section M1B Travel Time White Paper* included as Appendix A.

4.4 ITS DEVICES ALONG ADJACENT ROUTES

4.4.1 SR 0100

Table 3 lists the proposed ITS devices along SR 0100. The locations were reviewed with District 6-0 RTMC staff during a field view on September 14, 2016.

Device	Location
D100N_20	SR 0100 at Hanover Street split
CM-197	SR 0100 at Cedarville Road
D100S_21	SR 0100 south of Shoemaker Road
CM-200	SR 0100 at Shoemaker Road

TABLE 3: PROPOSED DEVICES ALONG SR 0100

D100N_20

Location: D100N_20 is a Type A DMS proposed to be located along SR 0100 NB near the Pottstown Pike / Hanover Street split.

Field of View: Northbound traffic on SR 0100 will have approximately 1,300 feet of tangent sight distance (16.1 seconds at 55 mph) to the DMS.

Communication and Power Sources: The DMS will be located near the Pottstown Pike / Hanover Street split, communication will be via a lateral 12-strand fiber optic cable to the existing 96-strand fiber optic cable along Hanover Street, and electric power is available along Hanover Street.

CM-197

Location: CM-197 is proposed to be located along SR 0100 NB at Cedarville Road and will be attached to the column of the signal mast arm on the northeast corner.

Field of View: CM-197 will be located to provide a field of view matching that of CM-198 (installed under SR 0422, Section M2C) to the north.

Communication and Power Sources: CCTV communication will be via a lateral 12-strand fiber optic cable to the existing 24-strand fiber optic cable along Cedarville Road, and electric power is available along Cedarville Road.

D100S_21

Location: D100S_21 is a Type A DMS proposed to be located along SR 0100 SB approximately 600 feet south of Shoemaker Road.

Field of View: Southbound traffic on SR 0100 will have approximately 2,000 feet of tangent sight distance (24.8 seconds at 55 mph) to the DMS.

Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the existing 12-strand fiber optic cable along Shoemaker Road. Electric power is available along Shoemaker Road.

CM-200

Location: CM-200 is proposed to be located along SR 0100 SB south of Shoemaker Road and in advance of D100S_21.

Field of View: CM-200 will be located to provide a field of view matching that of CM-199 (installed under SR 0422, Section M2C) to the south, as well as to provide visual confirmation of the proper operation of D100S_21.

Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the existing 12-strand fiber optic cable along Shoemaker Road. Electric power is available along Shoemaker Road.

4.4.1 PRIMARY ALTERNATE ROUTE: BENJAMIN FRANKLIN HWY – HIGH ST– RIDGE PK

Table 4 lists the proposed ITS devices along the primary alternate route comprised of Benjamin Franklin Highway, High Street, and Ridge Pike. The locations were reviewed with District 6-0 RTMC staff during a field view on August 22, 2018.

Device	Location
CM-4038	High Street (SR 4038) at Grosstown Road
CM-4037	High Street (SR 4038) at Hanover St.
CM-4036	High Street (SR 4038) at Armand Hammer Boulevard
CM-4035	Ridge Pike (SR 4038) at Rupert Road
CM-4034	Ridge Pike (SR 4038) at Lewis Road
CM-4033	Ridge Pike (SR 4038) at Swamp Pike
CM-4032	Ridge Pike (SR 4038) at Township Line Road

TABLE 4: PROPOSED DEVICES ALONG PRIMARY ALTERNATE ROUTE

CM-4038

Location: CM-4038 is proposed to be located on top of the signal mast arm on the NW corner of the intersection.

Field of View: CM-4038 camera support arm should be in line with the mast arm to minimize any impact on the field of view.

Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the existing 48-strand fiber optic cable along High Street. Electric power is available at the intersection.

CM-4037

Location: CM-4037 is proposed to be pendant mounted to the mast arm on the SW corner of the intersection.

Field of View: CM-4037 camera support arm should be in line with the mast arm to minimize any impact on the field of view.

Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the existing 48-strand fiber optic cable along High Street. Electric power is available at the intersection.

CM-4036

Location: CM-4036 is proposed to be pendant mounted to the mast arm on the NE corner of the intersection.

Field of View: CM-4036 camera support arm should be in line with the mast arm to minimize any impact on the field of view.

Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the existing 48-strand fiber optic cable along High Street. Electric power is available at the intersection.

CM-4035

Location: CM-4035 is proposed to be located on top of the signal mast arm located in the island on the Evergreen Road approach.

Field of View: CM-4035 camera support arm should be oriented to form a "V" with the lighting davit arm.

Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the existing 48-strand fiber optic cable along Ridge Pike. Electric power is available at the intersection.

CM-4034

Location: CM-4034 is proposed to be located on top of the signal mast arm on the SE corner of the intersection.

Field of View: CM-4034 camera support may require an extension of the mast arm column.

Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the existing 48-strand fiber optic cable along Ridge Pike. Electric power is available at the intersection.

CM-4033
Location: CM-4033 is proposed to be located on top of the signal mast arm on the NE corner of the intersection.
Field of View: CM-4033 camera support to be attached to the top of the mast arm column.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the existing 48-strand fiber optic cable along Ridge Pike. Electric power is available at the intersection.

CM-4032
Location: CM-4032 is proposed to be located on top of the signal mast arm on the NE corner of the intersection.
Field of View: CM-4032 camera support to be attached to the top of the mast arm column and oriented toward the center of the intersection.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the existing 48-strand fiber optic cable along Ridge Pike. Electric power is available at the intersection.

4.4.2 SECONDARY ALTERNATE ROUTE: PA 724 – PA 23

Table 5 lists the proposed ITS devices along the secondary alternate route comprised of PA 724 and PA 23. All locations except CM-2317 were reviewed with District 6-0 RTMC staff during a field view on August 22, 2018. CM-2317 was later requested by Phoenixville Borough and it was discussed and confirmed with the RTMC that this camera would be beneficial.

Camera	Location
D724E_01	SR 0724 at PA100
CM-7243	SR 0724 at Hanover Street
CM-7242	SR 0724 at SR 0422 Ramps
D724E_02	SR 0724 at Spring Wood Golf Club
CM-7241	SR 0724 at Bridge Street
CM-2300	SR 0023 at Bridge Street (PA 113)
CM-2318	SR 0023 at Manavon Street (PA 29)
CM-2317	SR 0023 at Starr Street
CM-2315	SR 0023 at Pawling Road
CM-2310	SR 0023 at SR 0252

TABLE 5: PROPOSED DEVICES ALONG SECONDARY ALTERNATE ROUTE

D724E_01
Location: D724E_01 is proposed to be located adjacent to the eastbound SR 0724 lanes approximately 500 feet west of SR 0100.
Field of View: Eastbound traffic on SR 0724 will have approximately 1,350 feet of tangent sight distance (20.4 seconds at 45 mph) to the DMS.

Communication and Power Sources: Communication will be via a POTS. Electric power is available along EB SR 0724 at the site.

CM-7243

Location: CM-7243 is proposed to be located on the top of the traffic signal mast arm column on the NE corner of the intersection.
Field of View: CM-7243 may require an extension to the column and the camera mount should be oriented toward the center of the intersection.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the existing 48-strand fiber optic cable along PA 724. Electric power is available at the intersection.

CM-7242

Location: CM-7242 is proposed to be located on the top of the traffic signal mast arm column located in the island on the north side of PA 724.
Field of View: CM-7242 camera mount should be oriented toward the east and perpendicular to the mast arm.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the existing 48-strand fiber optic cable along PA 724. Electric power is available at the intersection.

D724E_02

Location: D422E_02 is proposed to be located adjacent to the eastbound SR 0724 lanes approximately 125 feet east of the entrance to the Spring Wood Golf Club.
Field of View: Eastbound traffic on SR 0724 will have approximately 800 feet of tangent sight distance (9.9 seconds at 55 mph) to the DMS.
Communication and Power Sources: Communication will be via a POTS. Electric power is available along EB SR 0724 at the site.

CM-7241

Location: CM-7241 is proposed to be located on the top of the traffic signal mast arm column located in the SE corner of the intersection.
Field of View: CM-7241 camera mount should be oriented toward the west and perpendicular to the mast arm.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the existing 48-strand fiber optic cable along PA 724. Electric power is available at the intersection.

CM-2320

Location: CM-2320 is proposed to be located on the top of the traffic signal mast arm column located in the SE corner of the intersection.
Field of View: CM-2320 camera mount should be oriented clockwise from the mast arm to provide a view along Bridge St. into Phoenixville.
Communication and Power Sources: Communication is available at the existing controller cabinet for the Bluetooth travel time reader located on the same mast arm column.

CM-2318

Location: CM-2318 is proposed to be located on the top of the traffic signal mast arm column located in the island of the intersection.

Field of View: CM-2318 camera mount should be oriented perpendicular to the roadway.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the existing 24-strand fiber optic cable along PA 23 or the 96-strand cable west of the intersection. Electric power is available at the intersection.

CM-2317
Location: CM-2317 is proposed to be mounted to the mast arm located on the SE corner of the intersection.
Field of View: CM-2318 should be installed between the signal heads to maximize its view along SR 23 and Starr Street.
Communication and Power Sources: Communication will be via a lateral 12-strand fiber optic cable to the existing 24-strand fiber optic cable along PA 23. Electric power is available at the intersection.

CM-2315
Location: CM-2315 is proposed to be mounted pendant style between the signal heads of the traffic signal mast arm located on the NE corner of the intersection.
Field of View: CM-2315 pendant camera mount will provide best field of view.
Communication and Power Sources: Communication is available at the existing controller cabinet for the Bluetooth travel time reader located on the mast arm column. Electric power is available at the intersection.

CM-2310
Location: CM-2310 is proposed to be mounted to the top of the traffic signal mast arm column located on the north side of the intersection.
Field of View: CM-2310 camera mount should be oriented to provide an unobstructed view along all three legs of the intersection.
Communication and Power Sources: Communication will be available via the proposed extension of the 48-strand fiber optic cable from the intersection of Country Club Road/Ferry Lane and PA 23. Electric power is available at the intersection.

5.0 ITS ARCHITECTURE CONFORMANCE

The National ITS Architecture provides a common framework for planning, defining, and integrating intelligent transportation systems. It is a mature product that reflects the contributions of a broad cross-section of the Intelligent Transportation Systems (ITS) community (transportation practitioners, systems engineers, system developers, technology specialists, and consultants). The architecture defines:

- The functions (e.g., gather traffic information or request a route) that are required for ITS.
- The physical entities or subsystems where these functions reside (e.g., the field or the vehicle).
- The information flows and data flows that connect these functions and physical subsystems together into an integrated system.

The Regional ITS Architecture (Delaware Valley Regional ITS Architecture, currently being updated) is a subset of the National ITS Architecture, which has been developed to meet the needs of the District 6-0 Region. This document is the result of extensive collaborative efforts by stakeholders within Pennsylvania and New Jersey.

The ITS Architecture is comprised of several ITS Subsystems, each of which is designed to complement the other components. ITS Subsystems are the primary structural component of the ITS physical architecture. The subsystems collect data, store and forward data, process data and integrate data elements. The subsystems are grouped into four (4) classes: Centers, Roadside, Vehicles, and Travelers.

For this project, compliance with the Regional ITS Architecture will include two ITS Subsystems (Center and Roadside):

Center Subsystems

The center subsystems provide management, administration, and support functions for the transportation network. These systems communicate with the roadside subsystem to gather, disseminate, and provide information to the traveling public. The center subsystems applicable to the SR 0422 Corridor project are Traffic Management, Emergency Management, and Information Service Provider. The center that is incorporated within the project is the District 6-0 RTMC.

The Traffic Management Subsystem communicates with roadside devices to monitor and manage the flow of traffic. This subsystem interfaces with the roadside devices to collect information via CCTV video and vehicle detector data, disseminate it at the RTMC, and then pass it along to the traveling public via DMS messages. The information collected by the Traffic Management Subsystem is also shared between the Emergency Management and Information Service Provider Subsystems for the coordination of incidents.

The Emergency Management Subsystem interfaces with the Information Service Provider and Traffic Management Subsystems to provide coordinated incident response involving multiple organizations. Real time information coming from the Traffic Management System assists identifying emergencies and dispatching the most appropriate resources for emergency response. Interfaces with Information Service Providers assist emergency responders in controlling traffic during incidents and emergencies.

The Information Service Provider Subsystem collects, processes and disseminates traffic information to system operators and the traveling public. For the purpose of this project, information will be gathered

from the Traffic Management subsystem, coming from the PennDOT 6-0 RTMC and provided to the public via DMS messages. This subsystem will also serve as a conduit to provide traffic information between the Traffic and Emergency Management Subsystems.

6.0 COMMUNICATIONS PLAN

The devices installed under the SR 0422, Section M1B project will communicate back to the RTMC through an expansion of the existing Open Transport Network (OTN) backbone system. This form of communication is preferable because its ring architecture provides for a redundancy in case a cable is damaged and also allows multiple devices to come back to the RTMC on a single cable.

The design approach for a communications system for the SR 0422 Corridor project will be consistent with PennDOT system architecture being used on other recent ITS projects. A dedicated fiber optic system supplemented with a leased T-1 service (for one device located in District 5-0 with no proximity to existing fiber) will best suit the needs of PennDOT as far as functionality, serviceability, and performance are concerned. The bandwidth demands for video alone dictate the need for a high-speed communications system. The system will be comprised of three major components: nodes, hubs and infrastructure (a combination of conduit, junction boxes and cabling). Each device will communicate to a node using an Ethernet cable. Video or data will then be transported to a hub on a fiber optic cable (or T-1 circuit, for one location), where it will be transferred to an OTN backbone network and relayed to the District 6-0 RTMC to be utilized for traffic management.

When deployed, the network will be configured in a diverse ring using fiber along Ridge Pike and SR 0100 / SR 0202 as the backbone to get back to the RTMC. Fiber along the primary alternate route (Ridge Pike / High Street) and secondary alternate route (PA 0724 / PA 0023) will serve as backup communication routes. This configuration provides network redundancy in the event of a malfunction or break of fiber.

Nodes

Each device (CCTV or DMS) or combination of closely-spaced devices (depending on location) shall be considered a node. Each node will consist of a weatherproof traffic cabinet of sufficient size to contain the necessary components to power, protect, and transport signals from each device to its designated hub. Each device will terminate using copper cabling to an Ethernet switch, which will translate video or data signals and transport them via fiber optic media to a hub where it will interface with the SONET network. Each node will utilize two (2) strands of the backbone fiber optic cable and each strand will be terminated to a small termination tray where it will be used for required or future equipment.

It is being recommended that all CCTV and DMS utilize Internet Protocol (IP) (Ethernet) to connect back to OTN nodes. This is in line with the installations in similarly complex projects as well as District 6-0's recent conversion to a digital video management system.

A new fiber ring network will be designed under Section M1B to multiplex and network all proposed devices along SR 0422 mainline and its two alternate routes. This involves designing a communication network utilizing a fiber optic backbone system along SR 0422 from the Pottstown area to the existing splice cabinet on SR 0023 (Valley Forge Rd). Within this section of SR 0422, there are existing ITS devices (including analog cameras) that are set up in point-to-point and serial format. These existing devices were installed under the SR 0202, Section 400 projects and are approximated 20-year-old devices. It would be advantageous to add them to the new network, which requires the upgrade of existing cameras to IP format as well as the conversion of all existing point-to-point connections to ethernet links so that the entire corridor can be part of an overall new network. The new network will improve reliability and help

improve operations and maintenance of ITS infrastructure along the SR 0422 Corridor. The proposed upgrade will be as follows:

- Retrofit the existing DMS (D422E_01 and D422E_02) with port servers and hardened layer 2 network switches.
- Upgrade existing CCTV cameras (CM-402, 403, 404, 405, 406, 407, 408, 409 and 410) to High Definition IP units (some mount modifications may be required), replace camera to cabinet wiring, and replace the fiber optic media converter with a hardened layer 2 network switch. Design new 12-strand backbone drop cables and splicing details to the existing and proposed devices.

For the location where a leased service is required, the design team will coordinate with the broadband utility to facilitate a connection. At the hub location, a router with IP and T-1 interfaces will be required to convert the signal into a format that can be integrated in the OTN network. Demarcation points for the T-1 circuit must be located within 1,000 feet in advance of the proposed ITS device and hub locations to ensure continuity of the signal between the hub/device and demarcation point. It is anticipated that the T-1 interface will be a temporary connection intended to have the device online prior to the ability to install dedicated fiber. After fiber optic service in the area is completed, it is anticipated that the device will be cutover and T-1 service discontinued.

Hubs

It is anticipated that all proposed devices will integrate into the extended OTN network at the existing hub cabinet located along southbound Hanover Street, just south of the SR 0422 overpass. This cabinet will receive electric service under the SR 4031, Section PSS project and will also be retrofit into a communications hub. The proposed communications hub will be configured into the existing SR 0202 OTN SONET network as a diverse ring extension.

Groups of individual devices converging to a node will transmit signals to a remote hub. The hubs act as concentrators, and their locations are selected in a way that minimizes node and device distances from the hubs, reducing the amount of required fiber and providing for future network expansion. The field hub location will consist of an independently equipped Ethernet communications device capable to segmenting and allocating bandwidth to multiple devices and systems.

The hub will be a consolidation point for local devices and designated nodes, which will eliminate the need to have sophisticated communications equipment at each device location or node. This architecture is a cost-effective solution that will reduce the complexity of the network. Once the signals from each node have been transferred onto the backbone, they will be sent to the District 6-0 RTMC for observation and analysis.

Infrastructure

Infrastructure will consist of conduit, junction boxes and cabling. Conduit and junction boxes along the SR 0422 Corridor will be installed throughout several roadway construction projects: Sections M1A and n M2A (completed); Sections M2C and PM2 (currently in construction); and Sections M1B, M03, and M2B (future projects). Additional conduit will be installed to connect ITS device lateral cables. Fiber optic cable installations will be both underground and aerial.

To accommodate future reconstruction under Sections M2B and M03, a temporary 24-strand aerial fiber optic cable will be installed between the Hanover Street and SR 0724 Interchanges. Between the SR 0724

Interchange and the Porter Road bridge, a 144-strand backbone fiber optic cable will be installed in existing conduit and junction boxes installed under Section M1A. Between the Porter Road bridge and the Evergreen Road Interchange, the 144-strand cable will be installed in conduit and junction boxes to be installed under Section M1B. From the Evergreen Road Interchange to just west of Royersford Road, the 144-strand cable will be installed in conduit to be installed by Section PM2. At Royersford Road, the backbone will be installed in existing conduit and junction boxes and will be routed to the existing splice cabinet at the SR 0023 (Valley Forge Road) Interchange. The existing 24-strand cable within this section will be replaced with the 144-strand cable.

Underground cable installations, if any, will be minimized at the proposed device locations along SR 0100 and the alternate routes. Two lengths of aerial fiber optic cable are proposed to be installed on existing poles along the secondary alternate route to extend PennDOT's fiber to the proposed devices where needed. These sections are along SR 0724 from just west of Bridge Street to the SR 0023 Intersection, and along SR 0023 from Ferry Lane to SR 0252.

7.0 SYSTEM INTEGRATION AND TESTING

The purpose of the Integration Plan is to define interface requirements and information exchanges with planned and existing systems and subsystems (for example, subsystems and architecture flows as defined in the regional and National ITS Architectures). In addition, the agencies and other stakeholders participating in the development of the ITS architecture shall be identified. Finally, the level of effort required to fully integrate the new elements with existing systems shall be established.

The SR 0422 Corridor project is categorized according to its component devices and systems. This hierarchy is consistent with what is presented in the Communications Plan. Each category is then separated into existing, stakeholder, and integration sections. The existing section gives a general overview of any existing devices, both region-wide and within the project limits. The stakeholders section identifies those organizations and agencies (other than PennDOT) that have been identified in the functional requirements as having a vested interest in the development of that aspect of the system, as well as what those interests are. Finally, the integration requirements details what will be required to fully incorporate the proposed elements of the new ITS with the existing hardware, software, and institutional structures that already exist in District 6-0.

Integration requirements are divided into Communications, Software, and System integration categories:

- **Communications integration** includes making sure all the communications equipment is properly configured, connected, and tested. This report assumes that communications integration will be developed as part of communications design and provided as a service to the interfaces being communicated.
- **Software integration** includes revisions to or creation of software to provide portions of the interfaces needed between entities in the system. It includes relatively simple tasks such as configuring software for a new device that is already supported, to complex tasks such as developing support for new kinds of devices and sharing data and control between agencies.
- **System integration** is assembling the software and hardware elements and subsystems to make sure that all the components work together and conform to the design.

With the new system well defined in the Functional Requirements and Communications Plan, the next step in the Systems Engineering process is to identify any interfaces that will need to be provided, and a plan for how new systems will be integrated with their existing counterparts.

7.1 INTEGRATION OF FIELD DEVICES

All elements of the SR 0422 Corridor project will be designed with the intent of integrating into existing District 6-0 ITS operations to the extent that similar systems will be able to communicate with each other as well as the District 6-0 RTMC. As such, the CCTV, DMS, and TT systems will be designed in order to allow for future expansion of these systems throughout the surrounding area.

Prior to, during, and after installation of the CCTV and DMS, acceptance testing will be performed to verify the operational performances of the components are met. In general, acceptance testing should take place in three stages such that problems are identified corrected early on in the deployment process: preliminary/factory testing, site acceptance testing, and system acceptance testing. For each level of testing, a test plan should be developed based on the performance criteria, specifications, and

requirements of the system's elements. Furthermore, all elements should be retested periodically after system upgrades or additions of new devices. The District will reserve the right to waive any testing requirements at their discretion if the devices being provided have been successfully proven within the District.

7.1.1 CCTV CAMERAS

Communications Integration

CCTV Cameras will be connected by Ethernet cable to either a fiber optic switch or directly to a OTN communication hub. In the case of a fiber optic modem, the video will be transmitted over fiber from the modem to the local OTN hub. It is anticipated that the encoding of CCTV video will be done by the device itself, otherwise an encoder will be required within the cabinet. The current ITS construction standards allow for both approaches with IP video.

Software Integration

CCTV cameras will have digital video and PTZ interfaces and use the existing Genetec platform for distribution and control. As such, no major software modification will be necessary to integrate them into the existing system. Some minor configuration updates and enhancements will be needed to ensure that the video management software can accept and select the new video feeds. This project will utilize the modified ATMS integration specification which is part of Publication 408 and include Genetec platform as a modification.

System Integration

The new CCTV cameras will be transmitted over the OTN Fiber Optic Network. From the hub and other existing receivers located at the District 6-0 RTMC, the video feeds are connected to the input side of a local Genetec server. This Genetec platform distributes digital streams, over the network, to various operator/non operator workstations as well as to the video wall at the RTMC. Once the new cameras are added to the Genetec system, it will be possible to select and view them in the same manner as the existing video feeds. The District 6-0 video control and distribution system is fully digital and transmitted to the PennDOT server farm in Harrisburg (through an existing connection) for dissemination and distribution statewide to all District TMCs and other video sharing partners.

7.1.2 DMS

Communications Integration

DMS will be connected by fiber optic cable to an Ethernet switch where the data will be transmitted over two strand fiber Ethernet loop from the modem to the local OTN hub.

Software Integration

The ATMS software currently operates the DMS installed throughout the District. If the new DMS are of the same manufacturer any other signs used throughout the District, only minor software integration will be needed. In the event that a new manufacturer is utilized, the new sign will need to be NTCIP compliant, and a driver written so that the ATMS software can control the sign. If this is the case, then it will be the responsibility of the Contractor to coordinate with the ATMS vendor for the development of the driver under Task H of the Statewide ATMS Contract. This project will utilize the new standard ATMS integration specification which has been added to Publication 408.

System Integration

Data from the new signs will be transmitted over the OTN Network. Data will be transmitted over a ring network in an IP Ethernet format. From the OTN hub and other existing receivers located at the RTMC, the data is aggregated at the communications Hub in the field. From the device nodes or from the Hub, all data communication will be Ethernet interfacing with the ATMS control software. The ATMS software initiates commands to the field devices and reads the data that the devices send back. The interface at the Hub or at the device node there will need to be Ethernet interface to accommodate the additional signs that are being added under this project. The upgrade may be new Server cards, high-end managed Ethernet switch, or digital interface at the node level. In any case, once the new signs are added to the server or switch, it will be possible to control them in the same manner as the existing devices.

7.1.3 THIRD-PARTY VEHICLE PROBE DATA

Communications Integration

Third-party vehicle probe data will be provided directly to the ATMS software.

Software and System Integration

The ATMS software at the PennDOT District 6-0 RTMC has the capability of utilizing third-party data to generate travel times. This project will utilize the new standard ATMS integration specification which has been added to Publication 408.

8.0 SYSTEM OPERATIONS AND MAINTENANCE

PennDOT will be the primary operator and maintainer of the CCTV, DMS, and Travel Time systems. All operations of the system will be conducted out of the District 6-0 RTMC in King of Prussia, PA. The RTMC will be responsible for overseeing day-to-day activities relating to the operation of these elements.

It is anticipated that the maintenance of these devices will be carried out through the District's existing ITS maintenance contracts following all project testing and support periods. In keeping with the Statewide ITS Construction Standards, these test and support periods are assumed to be 60-days and 90-days, respectively. p

Table 6 presents the additional work items that PennDOT District 6-0 can assume will be added into the ITS Maintenance Contract, based on documented failure rates for similar systems in District 6-0.

Device	Quantity	Recommended Preventative Maintenance Calls (Per Device Per Year)	Documented Failure Rate	Anticipated Annual Maintenance Calls (Total System Per Year)
CCTV Camera	31	2	0.42	75.0
DMS	12	2	0.77	33.24

TABLE 6: ANTICIPATED ITS MAINTENANCE REQUIREMENTS FOR M1B DEVICES

9.0 PRELIMINARY COST ESTIMATE

Table 7 presents the anticipated costs for all ITS and Communications components as outlined in this report.

Item	UOM	Unit Cost	Quantity	Total Cost
CCTV Camera (Pole Mount)	EA	$50,000.00	15	$750,000.00
CCTV Camera (Signal Mast Arm Mount)	EA	$12,000.00	16	$192,000.00
DMS (Centermount)	EA	$110,300.00	7	$772,100.00
DMS (Type A)	EA	$60,700.00	5	$303,500.00
ITS Infrastructure				
Utility Pole	EA	$2,000.00	76	$152,000.00
Junction Box	EA	$2,500.00	97	$242,500.00
Fiber Optic Cable	LF	$8.25	161,194	$1,329,850.50
Trench & Backfill, Type I	LF	$19.00	17,500	$332,500.00
Existing Conduit Proving	LF	$2.65	81,677	$216,444.05
Fiber Make Ready	Dollar	$1.00	200,000	$200,000.00
Aerial Fiber Installation	LS	$472,500.00	1	$472,500.00
Unforeseen ITS Infrastructure Repairs	Dollar	$1.00	450,000	$450,000.00
Directional Boring	LF	$75.00	500	$37,500.00
Multiduct Conduit	LF	$8.00	8,700	$69,600.00
PVC Conduit	LF	$6.00	12,700	$76,200.00
Structure Mounted RMC Conduit	LF	$46.61	3,590	$167,329.90
Upgrade/Retrofit Existing Devices	LS	$105,000.00	1	$105,000.00
Splice Enclosure	EA	$1,000.00	40	$40,000.00
Fiber Optic Termination Panel	EA	$2,000.00	41	$82,000.00
ITS Power Supply	LS	$223,213.27	1	$223,213.27
Hub Modification (Field and RTMC)	LS	$100,000.00	1	$100,000.00
System Support Equipment	LS	$30,000.00	1	$30,000.00
RTMC Integration	LS	$155,000.00	1	$155,000.00
MPT	LS	$400,000.00	1	$400,000.00
			Subtotal	$6,899,237.72
Mobilization	LS	5%	1	$344,961.89
Contingency	LS	35%	1	$2,535,469.86
			Total	**$9,779,669.47**

TABLE 7: PRELIMINARY COST ESTIMATE

It should be noted that these costs reflect the preliminary conceptual layout for the ITS components. As further progress is made in the preliminary design and the calculation of quantities, this estimate is subject to change. In the event that the estimate exceeds the ear mark amount following the calculation of

quantities, then the implementation of ITS components will be prioritized so that elements can be scaled down or removed to accommodate the project budget.

Complex ITS Project: I-76 ITS Enhancements

I-76 ITS Enhancements

Variable Speed Limits & Queue Warning Systems Engineering Report

Pennsylvania Department of Transportation
Engineering District 6-0
Agreement E03207
Draft
January 20,2017

JACOBS

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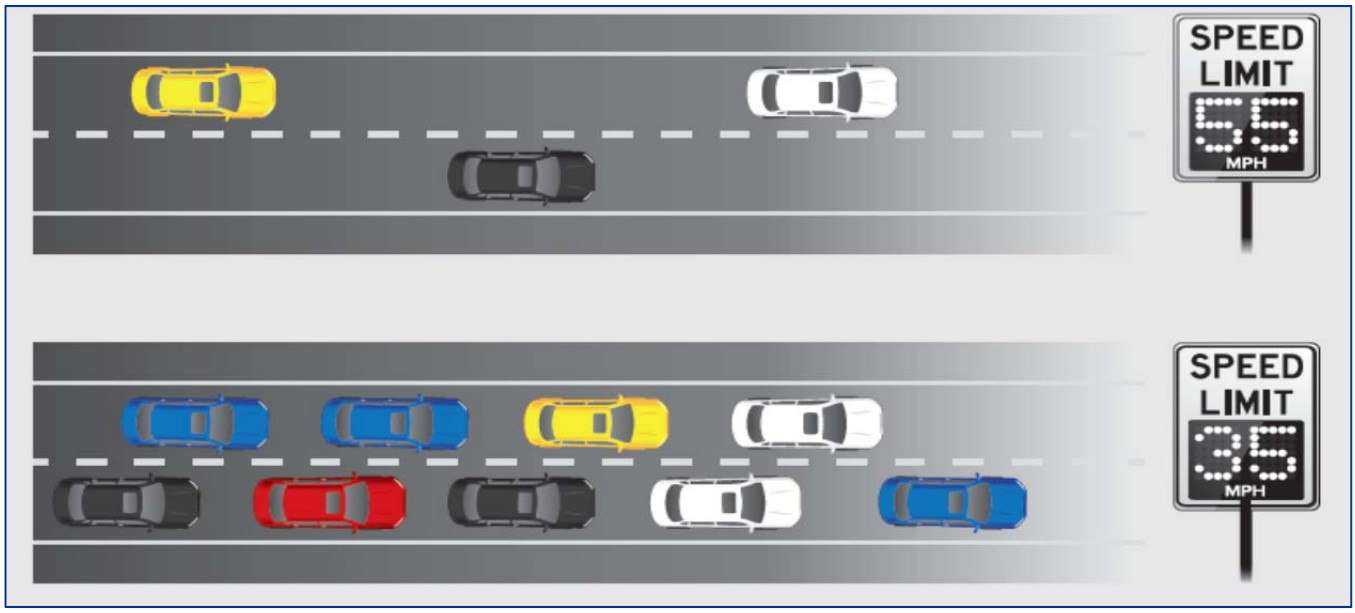

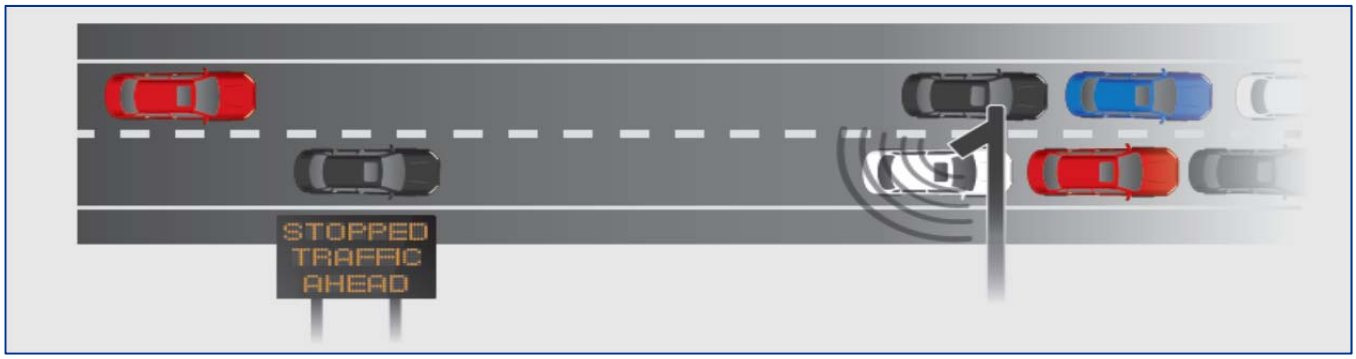

I-76 ITS Enhancements: Variable Speed Limits & Queue Warning Systems Engineering Report

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1. Scope

1.1 Introduction

1.1.1 Background

A Concept of Operations (ConOps) was completed in September 2016 by the Pennsylvania Department of Transportation (PennDOT) for potential Active Traffic Management Strategies (ATM) along the Schuylkill Expressway (I-76) between the PA Turnpike (I-276) and US 1 in Montgomery County and the City of Philadelphia. The ConOps was developed as part of the I-76 Corridor Comprehensive Transportation Management Plan Project. The ConOps identified a number of ATM concepts including:

- Variable Speed Limits
- Queue Warning
- Junction Control
- Dynamic Lane Assignment
- Part-Time Shoulder Use
- Ramp Metering
- Connected Vehicle Applications
- Multi-Modal Improvements
- Proactive Management of Traffic Signals along Adjacent Arterials

Variable Speed Limits (VSL) and Queue Warning (QW) elements were identified as Early-Action Initiatives and are the focus of this report.

1.1.2 Document Purpose

Systems engineering is a well-established project management methodology that provides a disciplined approach to building complex systems. It is a logical process that ensures that all activities in a project are conducted in a timely and economical manner. Systems engineering simplifies a project by merging management and technical activities within a single work process.

Using a systems engineering approach, the project team can effectively and efficiently process the specification, procurement, design, operation, and maintenance requirements for applying advanced technologies to transportation. Thus, by guiding an intelligent transportation system (ITS) project through an orderly and comprehensive process, systems engineering provides an ideal approach for implementing cutting-edge transportation solutions.

The United States Department of Transportation (U.S. DOT) understands the importance and benefits of using systems engineering. Consequently, as part of the Federal Rule/Policy on Architecture Conformity, a systems engineering approach is required on all federally funded ITS projects.

The benefits of using a systems engineering approach include:

- Easier development and implementation of ITS project requirements;
- Combination of technical and management activities into a single work flow;
- Simpler project tracking via a defined systems engineering process;

- More success meeting project schedule and budget targets;
- Improved communications with stakeholders, management, and technical personnel; and
- Satisfaction of the U.S. DOT rule that requires the use of a systems engineering approach for all federally funded ITS projects.

The Systems Engineering process begins with a Concept of Operations (ConOps) and continues through the V-Diagram (see **Figure 1**, following page) providing a traceable workflow as a way of relating the different stages in the system life cycle to one another, systems engineering may be described as a "requirements-driven development process", that is, the user (i.e. stakeholder) requirements are the overriding determinant of the system concept, design, and component selection as well as the implementation. The ConOps lays the foundation for early agreement among the stakeholders on all aspects of the system and establishes the basis for developing detailed system requirements. Establishing the framework up front avoids expensive, complex changes later in the project. Furthermore, application of the systems engineering process is a requirement for most ITS projects that involve Federal Aid.

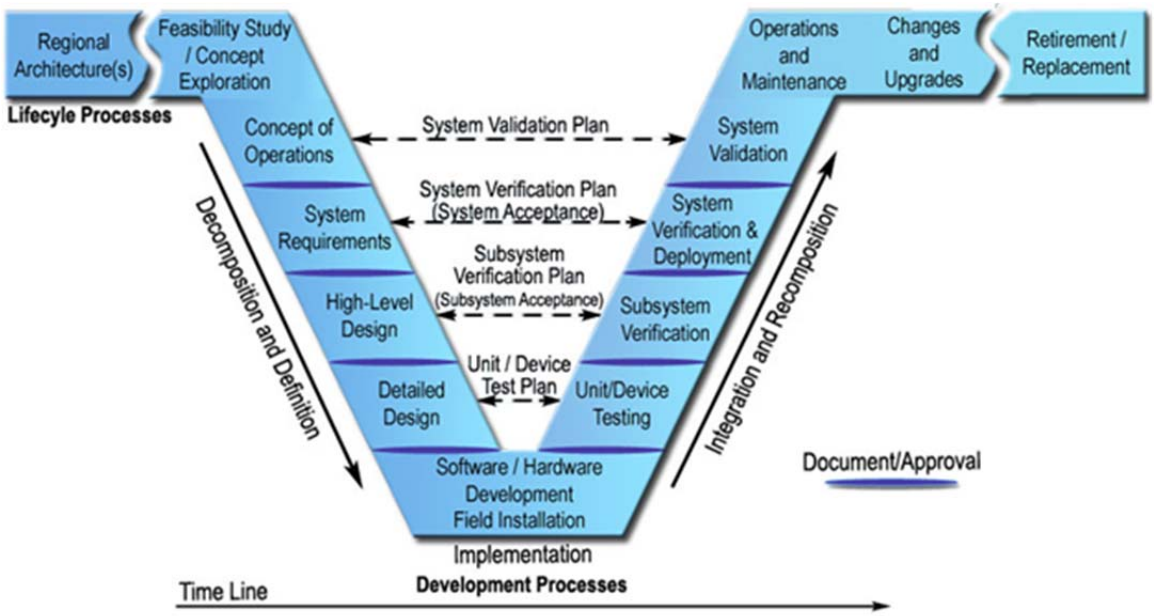


Figure 1: Systems Engineering Process Diagram

The systems engineering report is intended to be a living document that evolves throughout the course of the design. As additional detail is developed throughout the design, this document will continue to be updated.

1.2 Project Vision and Goals

The Vision and Goals remain consistent with the I-76 Corridor Comprehensive Transportation Management Plan ConOps.

1.2.1 Project Vision

The Project Vision represents the desired state of the Schuylkill Expressway Corridor, in terms of the overall intent and purpose of the program. In other words, if all goes well with the overall project and its subsequent implementation, then:

The traffic and transit operations of the Schuylkill Expressway Corridor will be managed seamlessly across multiple jurisdictional and agency boundaries, with the assistance of advanced technologies and cooperative strategies.

1.2.2 Project Goals

The VLS & QW systems will focus on the following goals identified under the I-76 Corridor Comprehensive Transportation Management Plan ConOps:

1. **Alleviate persistent recurrent congestion along the corridor** – There is identified persistent congestion throughout the limits of the corridor during both the weekdays and weekends. Congestion patterns originate at the major interchanges/traffic generators and propagate throughout the corridor. As such, ITS enhancements will be implemented in a manner to better utilize capacity at and between the three (3) major interchanges within the project limits.

2. **Better manage unbalanced traffic volumes** – ITS enhancements will be developed to better manage the fluctuation in traffic demand by intelligently allocating lane capacity to the highest vehicle demand. Strategies will also attempt to better guide vehicles into the appropriate lane in advance of off-ramps to reduce lane changing and weaving in highly congested areas.

3. **Reduce crashes, more specifically those related to rear-end collisions** – The Schuylkill Expressway has a higher than average prevalence of rear-end and total crashes throughout the corridor in both directions. Strategies will be developed to better alert drivers to queues in advance as well as harmonize vehicle speed throughout the corridor, especially approaching hazards.

1.3 Project Stakeholders

In addition to PennDOT, the key stakeholders to provide input in the development of the VSL & QW systems include:

- City of Philadelphia
- Federal Highway Administration (FHWA)
- Pennsylvania State Police (PSP)

1.4 Intended Audience

The intended audience for the I-76 VSL & QW Systems Engineering Report includes ITS professionals, traffic engineers, users of the I-76 corridor, and related stakeholders.

1.5 System Boundary

The system boundary addressed in this ConOps encompasses almost 13 miles of the Schuylkill Expressway from US 1 in the City of Philadelphia to the Pennsylvania Turnpike in Montgomery County (**Figure 2**).

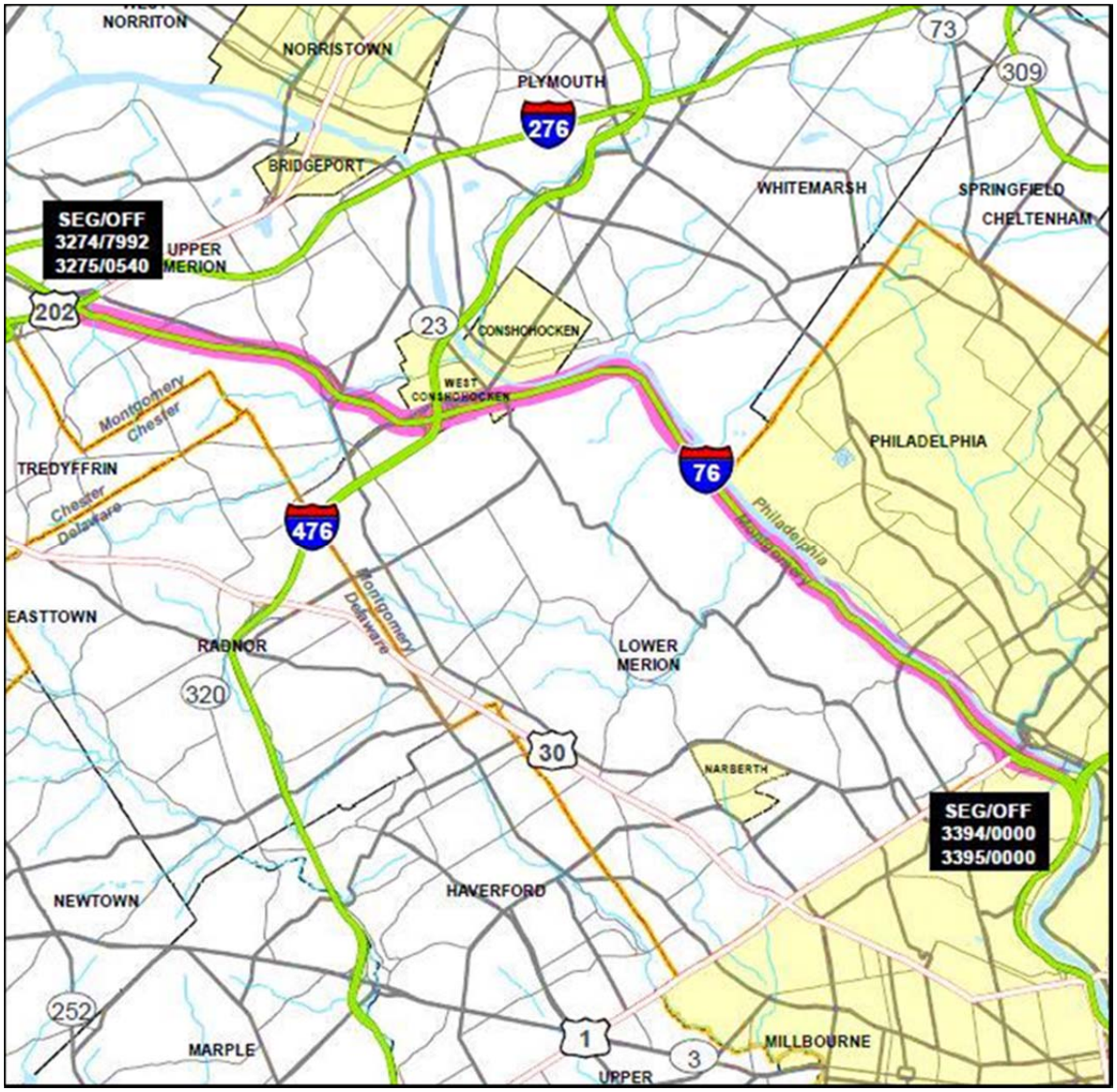


Figure 2: Project Limits

1.6 Document Organization

The Systems Engineering Report is divided into the following sections:

- **Section 2.0 – Description of the Current System –** Provides an overview of the I-76 corridor, traffic and accident history as well as PennDOT operational capabilities along the corridor.
- **Section 3.0 – Concept of Operations** – Provides a technical overview of the VSL & QW systems and an assessment of how they will likely work within the context of District 6-0 RTMC and ITS operations.
- **Section 4.0 – Functional Requirements** – Provides descriptions of what the system must do to address needs, provide a service, and/or facilitate a stakeholder responsibility**.**
- **Section 5.0 – ITS Device Locations and Preliminary Design Methodology** – Provides an overview of where ITS devices are proposed to be located, as well as an explanation of the design elements that were considered for each subsystem.
- **Section 6.0 – Communications Plan** – Describes at a high level how ITS devices will communicate with the RTMC.
- **Section 7.0 – Integration Plan** – Describes the high-level details regarding the integration of new devices into field work and software within the RTMC.
- **Section 8.0 – Maintenance and Operations** – Provides an overview of maintenance considerations that need to be considered to support the needs of ITS device deployments.
- **Section 9.0 – High-Level Cost Assessment** – Provides a preliminary cost estimate broken into logical work items based on the preliminary design package.
- **Section 10.0 – System Procurement** – Contains an explanation as to how the overall project is intended to be design and constructed.
- **Section 11.0 – Referenced Documents** – Lists the documents that were utilized as reference material when developing the Systems Engineering Report.

2. Description of the Current System

2.1 Interstate 76 (Schuylkill Expressway)

The Schuylkill Expressway is a multi-lane freeway that runs east-west and borders Center City Philadelphia on the west and south. It is the primary highway connecting the northwest suburbs, the City of Philadelphia and southern New Jersey. The study area limits include the Schuylkill Expressway between the PA Turnpike (I-276) to the west and US 1 to the east. PennDOT is responsible for the ownership and maintenance of the highway. The majority of the jurisdiction traversed in the study limits falls within Montgomery County, and a relatively short section falls within the City of Philadelphia. Within Montgomery County, I-76 travels through the municipalities of Upper Merion, Lower Merion, and West Conshohocken. There are generally two (2) travel lanes in each direction. The speed limit is primarily 55 miles per hour (MPH) within the study limits, although it reduces to 50 MPH at the US 1 interchange area within the City of Philadelphia.

The interchanges from west to east include:

- PA Turnpike (I-76 / I-276)
- Gulph Road
- US 202 / US 422
- King of Prussia / Norristown (WB only)
- Gulph Mills
- I-476 / Conshohocken
- Gladwyne (EB only)
- Belmont Avenue / Green Lane
- US 1 / City Avenue

2.2 Traffic Operations

A high-level overview of traffic operations within the project limits can be found in the I-76 Corridor Comprehensive Transportation Management Plan ConOps.

2.3 Crash Analysis

A high-level crash analysis within the project limits was developed under the I-76 Corridor Comprehensive Transportation Management Plan ConOps. Relevant data for the proposed VSL & QW systems is included within this section, and a map of the existing crash hotspots is included in **Appendix A**.

Crash data from 2009 to 2014 was analyzed to evaluate the crash history along the corridor study limits. Over the five-year period there were a total of 2,133 crashes reported, which equates to approximately 1.2 crashes per day.

Crash data was evaluated for each of the 50 highway segments within the study limits. Of the 50 segments, 15 segments (30%) had a total crash rate exceeding 200% of the statewide average. The majority of accident types were rear-ends and hit fixed object crashes. 22 out of 50 segments (44%) experienced rear-end crashes at more than double the statewide average, while five (5) out of 50

segments (10%) experienced hit fixed object crashes at more than double the statewide average. The majority of high-frequency crash locations (those greater than double the statewide average) occurred around interchanges. The highest frequency crash location along the corridor was I-76 eastbound just past the I-476 interchange. This segment experienced total crashes at approximately five (5) times the statewide average rate; rear-ends were approximately nine (9) times the average rate, and hit fixed objects were approximately three (3) times the average rate.

The high incidence of rear-end crashes is clustered along the following roadway segments. The high-frequency crash segments were utilized to determine the locations of DMS to support QW messages as follows:

- I-76 EB Mile Post 330 to Mile Post 334.5
- I-76 EB Mile Post 337.5 to US 1 Interchange
- I-76 WB US 1 Interchange to Milepost 337
- I-76 WB Mile Post 334 to Mile Post 331
- I-76 WB Mile Post 329.5 to Valley Forge Toll Plaza

2.4 Existing TSMO and ITS

PennDOT Engineering District 6-0 has been actively involved in transportation systems management and operations (TSMO) and the supporting ITS technologies since the early 1990's. The Schuylkill Expressway includes the following TSMO and ITS technologies:

Traffic Flow Monitoring is used to support several TSMO strategies, including traveler information and incident and special event management. The information is obtained from several sources:

- Traffic detectors that consist of side-fired microwave sensors that provide traffic volumes, roadway occupancy, and an estimate of average speed. Traffic detectors consist of a combination of PennDOT installed detectors and Traffic.com installed detectors. This information is displayed on maps in the Regional Traffic Management Center (RTMC).
- TRANSMIT E-ZPass tag readers that provide real-time measurements of average travel times between reader locations. This information is displayed as travel times on dynamic message signs (DMS).
- INRIX, through a negotiated agreement with the I-95 Corridor Coalition, provides average travel time and speed information for freeway links (i.e. between each interchange). This information is used for traveler information on the 511PA website and supplements E-ZPass data for travel time detection.
- Closed circuit television (CCTV) cameras provide RTMC operators with the ability to view the entire length of the Schuylkill Expressway to identify congested locations, verify incidents, and monitor response activities.

Traveler Information is provided by PennDOT and other public and private entities in a comprehensive manner, incorporating both pre-trip and en-route information including:

- PennDOT's 511 system (www.511pa.com) is the primary outlet for traveler information. 511PA provides users with real-time traffic information, transportation alternatives, and links to tourism hotspots across the Commonwealth. Internet and phone service offering real-time

traffic alerts, road conditions, and other alerts are part of the integrated 511PA system. PennDOT 511 traveler information is also available through the 511PA Mobile Application.

- DMS are installed along the Schuylkill Expressway, and are used to display travel time information and alerts to motorists in real-time.

The majority of mainline ITS infrastructure along the Schuylkill Expressway was constructed under the S.R. 0076, Section ITS project by PennDOT District 6-0, which was completed in 2009. The $25 million project included 44 CCTV cameras, 10 DMS, 25 vehicle detector stations, integration of 20 Traffic.com detectors, 18 travel time tag readers, and a high-speed fiber optic communications backbone.

Incident Management was the focus of the District's initial study and implementation of ITS as part of the Traffic and Incident Management System (TIMS) program starting in 1992. As such, incident management and the associated strategies have been a focus of the operations for over two (2) decades. Traffic flow conditions are monitored from the RTMC, and potential incidents are identified and verified. Phone and email communications, along with sharing video images between the RTMC and 911 centers, State Police, the City of Philadelphia, and other connected municipalities and stakeholders helps to promote timely responses.

A key component of PennDOT's incident management program is the use of Emergency Service Patrols (ESPs). ESPs support mobility by quickly responding to and clearing incidents and calling for other response resources as appropriate. In addition, they provide services to assist motorists (i.e. jump starts, gasoline, fluid for overheating radiators, tire changes, access to telephone for tow services) and are responsible for removal of roadway debris.

PennDOT also works closely with the DVRPC Incident Management Task Forces (IMTFs), which include the I-76 / I-476 Crossroads IMTF and Philadelphia IMTF within the study limits. The purpose of the IMTFs is to foster communication and cooperation between the organizations that are involved in responding to traffic incidents in these complex and congested interchange areas, to identify the incident management needs of those organizations, and to address those needs through funding, training, or other programs.

Another very useful tool developed by DVRPC in partnership with PennDOT District 6-0 is the web-based interactive Detour Route Mapping (iDRuM) system that organizes all existing PennDOT Emergency Detour Routes in Southeastern Pennsylvania into a manageable, easy-to-use interface. DVRPC has worked with PennDOT District 6-0 to update and reformat the detour route maps for all limited-access highways in the region, replacing outdated paper maps with digital PDF maps.

Regional Information Sharing is an important consideration in a large metropolitan area, particularly one that includes multiple States. DVRPC has been instrumental in developing an important tool in this regard – the Regional Integrated Multi-Modal (RIMIS) project. RIMIS is a web-based information exchange network with the ability to connect highway operations centers, transit control centers, and 911 call centers in the Delaware Valley, including PennDOT District 6-0. The objective of RIMIS is to foster better communications and information sharing between the many agencies in the region. PennDOT District 6-0 led the development of a private communications network that connects all of the major transportation centers in the region including County 911 centers, City of Philadelphia Streets Department Traffic Operations Center (TOC) and other City Agencies (Emergency Operations Center (EOC), Philadelphia International Airport (PHL), Philadelphia Police Department (PPD)),

Southeastern Pennsylvania Transportation Authority (SEPTA), Delaware River Port Authority (DRPA), and Delaware Department of Transportation (DelDOT). The private communications network allows these agencies to share data, including CCTV camera images, as well as video conference during incidents.

2.5 RTMC Operations and Interfaces

The PennDOT District 6-0 RTMC is located in the PennDOT Engineering District 6-0 Office Building in King of Prussia, and it operates 24 hours a day, and seven (7) days a week. The RTMC facility includes an operations control room, workstations, storage area, equipment room, and an adjacent conference room that doubles as an incident command center (ICC) for winter/snow removal operations and other incidents as needed. The RTMC control room includes six (6) operator workstation positions situated in three (3) rows of two (2) consoles in front of a ceiling-high video wall arranged in an arc across the front of the room. The video wall is used to display real-time, map-based graphic displays of traffic flows, congested segments, incident locations, DMS messages, and CCTV camera images. The workstations are used by operations supervisory staff, which has a clear view of the control room to monitor operations. The RTMC video images and traffic information is shared directly with incident management responders and with traffic information providers, including the PSP, PPD, County 911 Centers, PennDOT County Maintenance Offices, DRPA, DelDOT, NJDOT, and municipal police departments.

The RTMC typically operates with three (3) to four (4) operators during the first and second shifts (daytime) and three (3) operators during the third shift (overnight). The operations are split up by regions, with each operator assigned a region within District 6-0 to manage. Each operator monitors and controls all ITS systems assigned within their region. Staff assignments are not split up by application, so each operator has to be trained on the operation of all the systems controlled within the RTMC.

The RTMC operators are provided under a consultant staffing agreement. In addition to RTMC operators, PennDOT has four (4) full-time personnel assigned to the RTMC. One (1) of the PennDOT employees primarily provides field services, and the remaining three (3) are full-time at the RTMC facility.

2.6 ATMS Software

The RTMC has recently implemented a new advanced traffic management system (ATMS) software package (developed and integrated by Q-Free) that provides traffic monitoring, incident response management, video management, and DMS management capabilities. The new ATMS software, in its current configuration, does not include algorithms for VSL and/or QW.

3. Concept of Operations

The ConOps provides a technical overview of the VSL & QW systems and an assessment of how they will likely work within the context of District 6-0 RTMC and ITS operations. The deployment of VSL & QW along this corridor is being undertaken to expand the District's traffic and incident management system (TIMS) along this vital link in the regional transportation network. All new device deployments are intended to serve as a logical continuation to the ITS developed throughout the region as a whole and more specifically on surrounding highways and arterials. The VSL & QW components installed along I-76 will be used to more efficiently respond to traffic congestion and incidents along or affecting these roadways and provide motorists with real-time traveler information.

3.1 User Oriented Operational Description

A user-oriented ConOps enables the project team to gain valuable insight into the needs of the systems-users. To fully understand the operational needs of this system, we must understand who the users are. The perspectives of the users were developed through discussions with the project team, previous projects, and reference data.

3.1.1 PennDOT RTMC

The PennDOT RTMC operators are responsible for the daily operations of I-76 ITS which include:

- Monitoring of traffic flow and incident detection on the expressway and lateral connections.
- Verification of incidents through video surveillance system and audio communications.
- Enactment of response plans consistent with current PennDOT practices.
- Dissemination and display of traveler information.
- Documenting traffic/incident status and occurrences as necessary.
- Returning traffic operations to normal conditions following an incident or event.
- Coordination/Dispatch of Expressway Service Patrol Vehicles.

These daily operations are carried out from the RTMC workstations with integrated computer and communications support on a 24 hour-7 days a week basis. In addition to the duties described above, the operators must also coordinate with 9-1-1 Dispatchers, PSP Dispatchers, and other remote users.

Expressway Service Patrols operate along I-76 throughout the limits of this project. Service Patrol vehicles expedite the removal of disabled vehicles and non-hazardous debris from the travel lanes and shoulders. Service Patrols also play a key role in the identification and initial response to incidents along the expressway.

3.1.2 City of Philadelphia Streets Department

The City of Philadelphia Streets Department currently manages the operations of approximately 3,000 traffic signals throughout the City. They also manage CCTV cameras, Bluetooth detection devices, and transit signal priority along select corridors.

The City recently completed the construction of their Traffic Operations Center (TOC), which now serves as their hub for traffic management and incident response city-wide. The TOC is integrated directly to the PennDOT RTMC including the bi-directional sharing of video, traffic signal data, and detection data between agencies.

3.1.3 DVRPC

The DVRPC is the regional planning organization covering the five-county Southeastern Pennsylvania region as well as four counties in southern New Jersey. The DVRPC supports ITS and traffic operations initiatives throughout the Delaware Valley Region by administering the Transportation Improvement Program (TIP), Regional ITS Architecture and Long-Range Transportation Plan. In addition, DVRPC currently owns and maintains a VISSIM model of the entire corridor and is currently testing various operational enhancements that will be used to validate the operational concepts identified in the introduction and further detailed in the following sections.

3.1.4 FHWA

FHWA supports PennDOT in the design, construction, and maintenance of the Schuylkill Expressway. FHWA continues to ensure the highway is operated in a safe and efficient manner including oversight of any technology deployments. On a national level, FHWA provides guidance and resources for ATM research, standards, design, implementation and operations.

3.1.5 Montgomery County Planning Commission

The Montgomery County Planning Commission (MCPC) is a planning agency that coordinates with local communities as well as other government agencies to further zoning, land development, transportation, and environmental conservation initiatives throughout Montgomery County. MCPC initiatives would benefit from capacity enhancements along the I-76 corridor and the agency would benefit from enhanced data sharing with PennDOT. Their location in Norristown may provide future opportunity to connect with PennDOT's communications network.

3.1.6 Municipalities (Upper Merion, Lower Merion, Plymouth, Whitemarsh, Bridgeport, Conshohocken, Norristown, and West Conshohocken)

Each of the municipalities within the project limits own, maintain and operate the traffic signals on the roadways adjacent to the Schuylkill Expressway. Throughout the corridor, the maintenance and operations of these signal systems is coordinated with PennDOT. Memorandums of Agreement are in place between PennDOT and the Municipalities regarding the operations of traffic signals during incidents and special events and the PennDOT RTMC has the ability to assume control of certain traffic signal systems overlapping municipal boundaries during events of regional significance.

The recently signed PA Act 101 provides PennDOT with the ability to install, replace, synchronize, time, own, operate, or maintain traffic signals along both state and local roadways. Act 101 also allows the Secretary of Transportation to identify a Pilot Program for PennDOT managed traffic signals, with notification in the PA Bulletin. While not directly related to the VSL and QW deployments, signal control is being further examined through the overall I-76 Integrated Corridor project.

3.1.7 Pennsylvania State Police

PSP currently performs traffic enforcement activities along the Schuylkill Expressway. In addition, they routinely coordinate with PennDOT and other stakeholders for the security and quick clearance of incidents along the expressway.

3.1.8 SEPTA

SEPTA is responsible for the transit operations along the Schuylkill Expressway corridor. SEPTA currently manages all transit operations from their control center in Philadelphia. Under an ongoing initiative, SEPTA video will soon be available to PennDOT RTMC Operators. Other ongoing initiatives

to enhance operations between SEPTA and PennDOT include a direct fiber connection between agencies, which would allow for a more seamless bi-directional sharing of video and operations. Additionally, integrated parking applications are currently planned between the two agencies to better utilize capacity and SEPTA rail stations and make transit a more attractive alternative. The inclusion of transit information into dynamic messaging will require additional coordination with SEPTA's Control Center and Information Technology department.

SEPTA bus operations can potentially benefit from improvements to recurrent congestion. Creating greater consistency in on-time performance would boost Routes 124 and 125 from their upper 60 - low 70 percent on-time record. Reducing crash delays, particularly from secondary crashes that can occur, also creates a more consistent operating environment. Furthermore, having access to data about speeds on I-76 would assist SEPTA in long-term scheduling efforts.

In the longer term, SEPTA has plans to expand their Norristown High Speed Line into King of Prussia, which has the potential to reduce motor vehicle demand between Center City Philadelphia and the numerous retail and job generators in the King of Prussia Area.

3.2 Need for VSL & QW Enhancements

PennDOT Engineering District 6-0 has been actively involved in TSMO and the supporting ITS technologies since the early 1990's. The District is actively utilizing the following technologies along the Schuylkill Expressway:

- Traffic Flow Monitoring
  - Traffic Detectors
  - TRANSMIT E-ZPass Tag Readers
  - INRIX
  - CCTV Cameras
- Traveler Information
  - 511
  - DMS
  - Media
- Incident Management
  - ESPs
  - IMTFs
  - iDRuM
- Video Sharing
  - CISCO VSOM Software
- Regional Information Sharing
  - RIMIS
  - EOCs
  - Inter-Agency Communications Network

The mainline ITS infrastructure and high-speed communications network along the Schuylkill Expressway that was constructed by PennDOT District 6-0 in 2009 provided the infrastructure to support the TSMO efforts and has significantly improved operations along the corridor. Now that the infrastructure is in place and the District and regional stakeholders have optimized its current capabilities, there is the ability to pursue enhancements based on operational needs that the current

system does not provide. The VSL & QW systems were identified based on the current system deficiencies. The VSL & QW systems will help support the following needs identified through the I-76 Corridor Comprehensive Transportation Management Plan ConOps:

1. **A Mechanism to reduce mainline speeds.**

2. **Advanced warning of congestion and incidents.**

3.3 Proposed Concepts

This section provides high-level details regarding the VSL and QW strategies that address the need for ITS enhancements. This section focuses on the technology, components, applications, and standards for each strategy.

3.3.1 Variable Speed Limits

VSL are communicated to the motorists by signs that include a post or overhead mounted two-character dynamic messaging device. In more advanced applications, VSL includes the integration of traffic data into a back-end software system that either automatically modifies speeds in response to traffic conditions or provides notifications to RTMC operators who manually modify speed limits through a central user interface. In addition, VSL requires a communications network connection back to the RTMC.

3.3.1.1 VSL Components

A VSL system includes the following components:

- Vehicle Detection Device – An automated VSL requires vehicle detection for volume, speeds and/or occupancy along the corridor to operate effectively. The Schuylkill Expressway is currently outfitted with microwave vehicle detection devices, as well as probe data from E-ZPass tag readers and INRIX.
- Video coverage – Video coverage is not required, but is helpful in verifying and monitoring conditions back at the RTMC.
- VSL Display Device – Typically a two-character matrix dynamic message sign. Many times these signs are combined with static speed limit signs, and some agencies, such as the New Jersey Turnpike Authority utilize larger, full-matrix DMS that are configured to mimic a static sign.
- VSL Support Structure – Typically, VSL devices are mounted on vertical posts or overhead gantries or sign structures.
- Power and Communications Infrastructure – VSL devices are low-power, low-bandwidth devices (in general) so the power and communications requirements are relatively minor. VSL systems can be powered by either solar or hard wired sources and can communicate via either Ethernet, serial, cellular, or leased line data.
- Back-end command and control system – Typically an ATMS software application. PennDOT's current software provider, Q-Free, currently provides a VSL module for their software, although it is not currently installed as part of PennDOT's current ATMS software package.

3.3.1.2 VSL Applications

Studies on the use of VSL technology have shown that accident reductions of 10% to 30% can be expected through the implementation of VSL. VSL is a technology that has been widely deployed throughout Europe and parts of the United States. The application areas for VSL deployment typically cover one (1) of two (2) scenarios:

- The deployment of VSL along an entire corridor to completely replace static speed limit signing. Local examples of similar deployments include I-495 in Delaware and the New Jersey Turnpike. In these examples, VSL devices are typically located at regular intervals along the roadway. Research from Europe and the United States shows that a typical VSL device spacing is approximately one device per quarter to half mile.

- The deployment of VSL approaching high-crash locations (especially high frequencies of rear-end crashes), locations with recurring queuing (especially those with limited sight distance), locations overly susceptible to changing weather conditions (such as bridges, steep hills, and low-lying areas), and work zones. In these instances VSL devices are located in advance of the area of concern in order to provide advanced warning to motorists and allow for a safe distance to decelerate prior to the queue or hazard.

3.3.1.3 VSL Standards

VSL deployments are governed by the Manual on Uniform Traffic Control Devices (MUTCD), as regulatory signage. In addition, Pennsylvania Code 212.108 (see **Appendix B**) permits the use of VSL. The code does however stipulate that speed limit signs cannot be located at a spacing of greater than a half mile, and that speed limits must be displayed at each VSL location along the roadway at all times. This requires that a VSL system be permanent and continuously operated at all times. VSL deployment also requires that all existing static signage be removed within the limits of VSL in order to provide consistency in speed limits throughout the route. In addition, the speed limit cannot be reduced by greater than 10 MPH without advanced signage. Specific weather and speed level adjustments will be developed with PennDOT and industry best practice during the development of the standard operating procedures for VSL implementation.

3.3.1.4 VSL Implementation along the Schuylkill Expressway

Due to the persistent and widespread daily congestion along the Schuylkill Expressway, as well as the high occurrence of rear-end crashes, PennDOT is pursuing VSL deployment as a corridor-wide implementation. This would necessitate the complete replacement of all static speed limit signs along the Schuylkill Expressway within the project limits. A survey of the PennDOT video log for the corridor indicated that there are currently 22 static speed limit signs along the Schuylkill Expressway within the identified limits. At minimum, these signs would be replaced with VSL and co-located with the nearest existing/proposed ITS device location in order to economize power and communications services. Additional signs will also be needed in advance of high-crash areas and to maintain adequate spacing for purposes of incrementally reducing speeds in advance of congestion in accordance with standards and industry best practice. Where co-location is not feasible, a new VSL vertical support structure will be placed adjacent to the roadway and new hard-wire power and fiber connection installed. Due to the requirement to keep VSL operational 24 hours per day / seven days per week, solar power would not be a practical alternative. It is anticipated that all VSL devices can be integrated into the existing Ethernet communications network installed under the S.R. 0076, Section ITS project.

Additional static signing will need to be installed along I-76 EB immediately after the PA Turnpike Interchange as well as I-76 WB prior to the US 1 interchange in order to notify motorists that speed limits will be variable ahead. In addition, PennDOT may consider installing notification signing at all interchange on-ramps within the limits of VSL deployment.

3.3.2 Queue Warning

A QW system collects and analyzes traffic data in order to issue automated warnings or other responses. In freeway applications, queue detection and warning is utilized to provide vehicles with an advance notification that they are approaching slowing or stopped traffic and that they should be alert for obstructions to their path.

3.3.2.1 QW Components

A typical QW system includes the following components:

- Vehicle Detection Device – These devices can utilize in-pavement sensors, radar sensors, video detection, probe data, or any other source to collect vehicle presence, speed, and occupancy. Vehicle detection devices are placed in strategic locations to locate the back of a queue of vehicles upstream of an incident or bottleneck in order to warn approaching motorist.
- Video coverage – Video coverage is not required, but is helpful in verifying and monitoring queues at the RTMC.
- Warning Display Device – These are the upstream devices that warn motorists to be aware that they are approaching slowed or stopped vehicles further down the roadway. These devices are typically dynamic but could include something as simple as a small blank-out sign with a predefined warning message to a full-size DMS. Many comprehensive ATM deployments utilize smaller DMS in conjunction with variable speed limits and lane use control in order to warn motorists of obstructions in the roadway.
- Power and Communications Infrastructure – QW detection devices are low-power, low-bandwidth devices in general so the power and communications requirements are relatively minor. Depending on the messaging device, more robust power may be required, however many detection devices can be powered by either hard wiring or solar. QW systems can communicate via either Ethernet, serial, cellular, or leased line data.
- Back-end command and control system – Back-end software is required for the operation of a corridor-wide queue warning system. Of specific importance is the algorithm used to generate the warning. A high frequency of false alarms will lead to less trust in the detection and thus reduce the effectiveness during a real scenario. The existing OpenTMS software installed in District 6-0 does have the ability to provide queue detection. Existing functionality will be referenced during system design and any required modifications or enhancements to meet design requirements will be included in the capital project.

3.3.2.2 QW Applications

QW systems are commonly used throughout the United States, most frequently in construction areas as part of Smart Work Zone Deployments. PennDOT recently piloted a QW system approaching the Platt Bridge from I-95 as part of a bridge rehabilitation project that closed one of the two lanes in each direction. The Pennsylvania Turnpike Commission currently uses a QW system to update drivers on conditions through work zones on both the East-West and Northeast Extension roadways of the Turnpike System. The primary goal of implementing a QW is to reduce the occurrence of rear-end crashes as a result of vehicles entering the back of a queue at a high rate of speed. When deployed

in conjunction with variable speed limits, QW can also help to harmonize speed in areas of stop-and-go traffic.

Throughout 2012 and 2013 the California Department of Transportation (Caltrans) utilized a QW system to alert motorist to backups resulting on heavy traffic attempting to enter a mall facility during peak holiday travel. Compared to the prior years, they documented a 66% reduction in the number of queuing related crashes after installing the system.

In 2010, Illinois DOT installed a work-zone queue detection system along 30 miles of I-55 and installed warning devices (portable DMS) up to six miles in advance of the work zone. Over two (2) years, they documented a 14% reduction in the number of rear-end collisions compared to a similar project that did not have a QW system.

QW is also being utilized by PennDOT as a component of its ramp metering system on I-476. Queue detectors at the end of the on-ramps detect when the queue of traffic is about to spill over onto the intersecting arterial roadway and prompt the ramp metering controller to speed up the release of vehicles until the queue dissipates.

3.3.2.3 QW Standards

There are no known standards regarding the design or implementation of permanent QW systems. However, in January, 2014, the FHWA published the Work Zone Intelligent Transportation Systems Implementation Guide which provides guidance for the usage of QW systems as part of Smart Work Zone installations.

Components of QW are however governed by PennDOT and FHWA Standards as follows:

- Detection Devices are identified in the PennDOT ITS Design Guide (Publication 646), as well as in the standard construction and integration specifications in Publication 408.
- Dynamic Signing Devices are governed by both MUTCD requirements, PennDOT ITS Design Guide (Publication 646), PennDOT Standard Specifications (Publication 408), as well as Standard ITS Design Drawings (Publication 647).

3.3.2.4 QW Implementation along the Schuylkill Expressway

The intent of QW systems is to reduce the rate of rear-end crashes. A review of five (5) years of crash data along the corridor indicated that 22 segments (44%) experienced rear-end collisions at greater than two (2) times the statewide average for similar facilities. The 22 segments with high-incidences of rear-end collisions will be the focus for the implementation. These locations are shown in the drawings included in **Appendix A** and fall within the following limits:

- EB Mile Post 330 to Mile Post 334.5
- EB Mile Post 337.5 to US 1
- WB US 1 to Mile Post 337
- WB Mile Post 334 to Mile Post 331
- WB Mile Post 329.5 to Valley Forge Toll Plaza

PennDOT's consideration is to utilize existing RTMS detection stations installed under the S.R. 0076, Section ITS project, as well as the integration of legacy detection stations previously owned by Traffic.com to provide speed, volume, and occupancy rates to use in queue warning algorithms.

These RTMS detection stations are capable of providing per lane vehicle occupancy refreshed every 20 seconds to 60 seconds. The integration of these detection stations include connection to the I-76 fiber network, upgrade of power supply, and replacement of the detection device if necessary. A full inventory and evaluation of these detection devices will need to be performed as part of the design activities. In addition, all detection devices along the corridor should be re-calibrated to ensure that they are currently operating properly and collecting accurate and consistent data.

It is anticipated that probe vehicle data provided by INRIX and currently purchased by the Department would also be utilized to supplement point detector data in the data analysis algorithm for use when detectors malfunction as well as to collect and provide historical data for use by the algorithm.
QW signing is anticipated to be provided via a mix of existing full-size DMS as well as the installation of eight (8) additional smaller-scale DMS to be utilized for queue warnings in advance of the areas highlighted above, as well as to provide any additional emergency notification or traveler information as required by the RTMC.

3.4 Operational & Support Environment

This section is provided to allow affected organizations to prepare for the changes that will brought about by the VSL & QW systems and to allow for the planning of the impacts on PennDOT, user groups, and the support operations and maintenance organizations. The support environment for the VSL & QW systems will be one that compliments the existing ITS support environment processes and capabilities of the agencies. The following section describes operational needs associated with the VSL & QW strategies, and the subsequent sections describe operational needs associated with hardware, software, enforcement, and public information.

3.4.1 DVRPC Operational Research Model Project

The DVRPC is currently engaged in a multi-year project to develop a baseline model and evaluate transportation improvement concepts along the I-76 corridor. This analysis is being conducted through the collection of traffic data and utilization of the VISSIM traffic analysis software tool. Recent projects have included the development of the Schuylkill Expressway Operational Research Model in 2012, the I-76/I-476 Crossroads Study in 2014, and the I-76/US 202/US 422 Lane Reconfiguration Study in 2015.

To that end, the DVRPC's 2016 modeling project is to evaluate part-time shoulder usage along I-76 in both directions between the PA Turnpike and US 1. The results of this analysis will help in the design process and layout for future implementation projects. In 2017, the DVRPC intends to update the shoulder usage model to include additional improvements discussed in this report to determine the effect of multiple ATM treatments operating in tandem, simulating the ultimate build condition for the I-76 Corridor Comprehensive Transportation Management Plan.

3.4.2 Variable Speed Limits

VSL should address traffic congestion before or during a breakdown in operations. Breakdowns in traffic can be caused by several factors including high demand, weather, work zones and incidents. Dynamic speed limits reduce rear-end collisions due to speed differentials caused by these breakdowns. In order to be deployed successfully, the operational needs for the VSL subsystem are at a minimum:

- Coordination with regulators and PSP to confirm VSL operational usage and enforcement.

- Static speed limit signs need to be removed from the project area.
- VSL signs need to be placed in a location such that speed limits are visible to all motorists.
- VSL signs need to be placed in a location viewable from a local CCTV camera in order to manually verify operation.
- VSL devices need to have a redundant power supply in order to assure continuous display of speed limits.
- Ensure a consistent supply of accurate and reliable traffic data to feed VSL algorithms.
- Archiving of vehicle speed data to identify areas where VSL enforcement is needed.
- Integration into existing PennDOT communications network to ensure connectivity to field devices.
- Implementation of a VSL software system at the PennDOT RTMC.
- Archiving of VSL data and generation of performance measures to evaluate the system.
- PSP Workstation at RTMC – archiving speed limit information for use in court cases and for use by on-site PSP personnel.

3.4.3 Queue Warning

Queue Warning installations should support the reduction in rear-end collisions throughout the corridor by providing advanced warning of downstream queues. In order to be deployed successfully, the operational needs for the QW subsystem are at a minimum:

- Ensure that proper detection coverage is in place to ensure the collection of data at locations with persistent queueing.
- Ensure that all detection devices are properly working and calibrated.
- Ensure that the queue detection algorithm is sufficiently calibrated to minimize the amount of false alarms.
- Ensure that dynamic signage is located sufficiently in advance of the queueing area to provide adequate warning and that signs are oriented and sized sufficiently to provide to provide clear and consistent messages.
- QW installation needs to be coordinated with variable speed limits in order to better harmonize speeds approaching queuing traffic.
- QW detection and signage will require a redundant power supply in order to assure continuous display of safety-related information.
- Implementation of a Queue Warning software module at the PennDOT RTMC. This software module should automatically generate and post queue detection warnings and provide an alarm to RTMC operators.

3.4.4 PennDOT Communications System

The communications network should serve both the current needs of the devices and future expansion of the TIMS system. The PennDOT District 6-0 Fiber Optic Network Master Plan recommends fiber optic cable as the high-speed communications medium.

More specifically, the operational needs for the communications subsystem are at a minimum:

- Provide highly reliable high-speed data and video links between field devices / communications hubs and the RTMC.
- Provide the ability for high-speed connections to control centers of stakeholders.
- Provide compatibility with existing PennDOT communications infrastructure and protocols.

- Provide communications network redundancy where feasible.
- Provide capability of transmitting multiple networks.
- Provide capability to integrate and connect with adjacent ITS deployments.
- Provide necessary bandwidth to support future ATM and connected vehicle initiatives.

3.5 Operational Scenarios

Operational Scenarios describe how VSL & QW strategies will operate under different circumstances. The scenarios presented do not represent every possible condition of the roadway but reflect typical events the VSL & QW systems will encounter. This should provide a better understanding of how the various VSL & QW strategies, traffic operators and patrol units work together to resolve issues and improve traffic conditions.

Traffic operators will play a key role in determining the appropriate utilization of VSL & QW strategies. Operators will rely on communication with patrol units or CCTV cameras to verify incidents and queueing and ensure that speed limits and warning messages are being disseminated properly. Furthermore, operators will be able to submit changes to the proposed VSL & QW plan, input additional data, and approve the VSL & QW plan before implementation. The extent of operator involvement will vary based on how much information is necessary for the given scenario.

The six (6) scenarios used in this section represent typical conditions the VSL & QW systems will encounter:

1. Free flow – No congestion or adverse conditions. Represents how VSL & QW strategies will operate/ display during normal conditions
2. Recurrent congestion (AM/PM) - occurs as use increases, and is characterized by slower speeds, longer trip times, and increased vehicular queueing. Represents how VSL & QW strategies will operate during AM/PM rush hour.
3. Lane Restriction – Lane closure due to work zone, accident, debris, etc.
4. Weather conditions – Represents how VSL & QW strategies will operate in reaction to icy roadways flooding, etc.
5. Complete closure – Full closure of all traffic lanes.
6. Non-recurrent congestion – Represents how VSL & QW strategies will operate when the roadway is congested during hours that typically have free flow traffic.

The VSL & QW systems work to reduce speed differentials that cause unanticipated speed reductions. This system steadily reduces the speed of traffic as it approaches a congestion area and warns drivers of congestion ahead. With this system, drivers anticipate reduced speeds, rather than unexpectedly coming upon congested, slow moving traffic. Differential speeds can cause rear-end collisions or sideswipes that cause further traffic congestion. The QW system utilizes the DMS to display warning messages to drivers.

3.5.1 Free Flow

During free flow conditions, VSL signs will display the normal posted speed limit (55 mph).

The DMS will be left blank or display travel time information.

3.5.2 Recurrent Congestion

During recurrent congestion, VSL signs will display speeds that ease upstream traffic speeds to that of the speed in the congestion area, by reducing speeds in a step-pattern. Upstream from the congestion, the VSL signs will display the normal speed limit. Closer to the congestion area, signs will start to display lower speeds (e.g. 55, 45, 40, etc.) as seen in the following figure. After the congestion, VSL signs will display increased speed limits to bring the traffic flow up to the normal speed limit. If the congestion occurs again downstream, VSL signs will display a speed limit between the congestion area reduced speed and the normal speed limit (between 40 and 50 for example). As traffic approaches the new congestion area, the VSL signs will again display a reduced speed. The VSL & QW will eventually utilize predictive traffic conditions to proactively manage the recurrent congestion scenario.

DMS will display a queue advisory upstream from the congestion area. Near the congestion area, DMS will display an imminent warning message.

3.5.3 Lane Restriction

When a lane restriction is in place, VSL signs will react similar to a congestion scenario by gradually reducing traffic speeds upstream of any queues that form due to reduced road capacity.

In general, the DMS will display a lane closure warning and queue warning upstream of the lane closure. The DMS may display a more specific message depending on the type of lane restriction (i.e. work zone, accident, debris, etc.).

3.5.4 Weather Conditions (Icy / Slippery Conditions)

Icy and slippery conditions may necessitate reduction of speeds, even if expressway flow is less than capacity for safety. If the system detects reduced speeds downstream, VSL sign will gradually slow down traffic similar to the recurrent congestion scenario.

DMS signs will display weather advisory messages throughout the corridor or in areas where ice is known to form.

3.5.5 Complete Closure

In the event of a complete road closure, VSL and DMS can be left blank or display a speed limit and “Road Closed” message respectively.

DMS located outside of the project limits, but approaching I-76 will need to notify motorists of the closure and provide detour information.

3.5.6 Non-recurrent Congestion

During non-peak hour congestion, the system will detect the reduced speed of traffic and react to the situation similar to how it would approach the recurrent congestion scenario by reducing speeds gradually in a step-pattern and warning drivers of imminent queues.

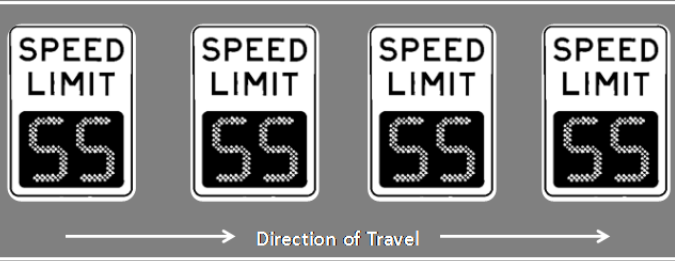
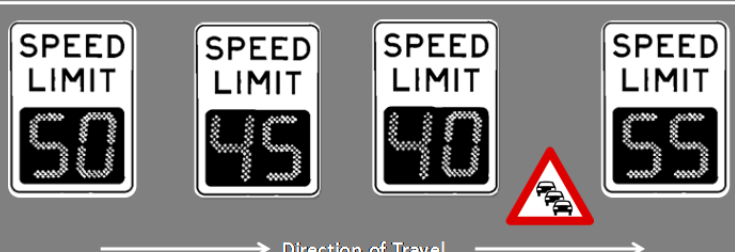
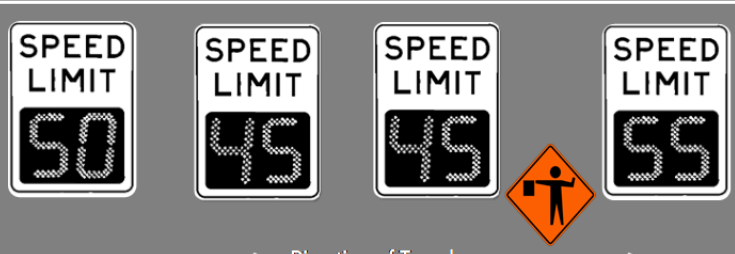
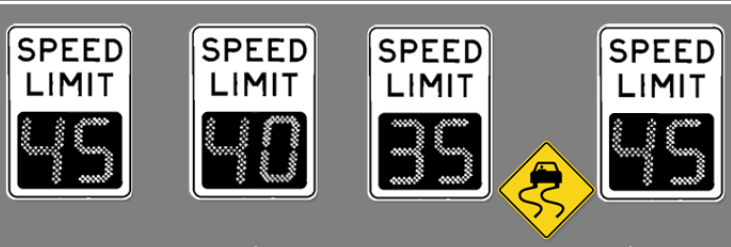
Scenario	Plan	Pattern
Free Flow	Under normal conditions VSL signs will display the normal posted speed limit (55mph)	
Recurrent Congestion	To manage congestion VSL signs will display reduced speeds upstream of congestion in a step pattern	
Lane Restriction	Reduce speed upstream of lane blockage in a step pattern	
Weather Conditions (Icy/ Slippery)	Icy and slippery conditions may necessitate reduction of speeds, even if expressway flow is less than capacity.	
Complete Closure	In the event of complete closure of all traffic lanes VSL signs will display the normal posted speed limit	See Free Flow
Non-Recurrent Congestion	Non-recurrent congestion will follow the same traffic pattern as recurrent congestion	See Recurrent Congestion

Figure 3: VSL Operational Scenarios

Scenario	Plan	Display		
Free Flow	Under normal conditions the DMS will be left blank or display a text message indicating the travel time to a specific exit or interchange		Or	TRAVEL TIME MESSAGE
Recurrent Congestion - Peak Hour	Far upstream from the congestion area the DMS will display a queue warning. Closer to the congestion area a reduce speed warning will be displayed.	CONGESTION 1 MILE Far		CONGESTION REDUCE SPEED Near
Lane Restriction	In general the DMS signs will display lane closure warnings upstream of the closure. The DMS may display a more specific message depending on the type of lane restriction (work zone, accident, debris)	RIGHT LANE CLOSED 1 MILE Far		RIGHT LANE CLOSED Near
Weather Conditions (Icy/ Slippery)	Icy and slippery conditions may necessitate reduction of speeds, even if expressway flow is less than capacity.	CAUTION WINTER CONDITIONS		
Complete Closure	In the event of complete closure of all traffic lanes DMS will be left blank beyond the closure			
Non-recurrent Congestion	During non-recurrent congestion DMS signs can display the recurrent congestion display seen above or an alternative display seen here.	STOPPED TRAFFIC AHEAD Far		BE PREPARED TO STOP Near

Figure 4: QW Operational Scenarios

4. Functional Requirements

The Functional Requirements provide a description of what the system must do to address needs, provide a service, and/or facilitate a stakeholder responsibility. A Functional Requirement is characterized by naming a system, the stakeholder, and presenting a list of "shall" statements that constitute the functions to be provided by the system. The Functional Requirements define how the needs of the stakeholders involved in the project will be met. They are designed to meet the Goals and Objectives stated in Section 1. The Functional Requirements are categorized by each stakeholder and systems that impact the respective stakeholder.

According to the FHWA publication *Developing Functional Requirements for ITS Projects*, an effective functional requirement should have the following characteristics:

- ***Necessary*** - All requirements must trace to at least one need.
- ***Concise*** - Stated in language that is easy to read.
- ***Attainable*** - A realistic capability that can be implemented for the available money, resources and time.
- ***Complete*** - All needs must be reflected by the requirements and not force the reader to look at additional text to know what the requirement means.
- ***Consistent*** - Does not contradict other stated requirements nor is it contradicted by other requirements.
- ***Unambiguous*** - Open to only one interpretation.
- ***Verifiable*** - Must be able to determine the requirement has been met through one of four possible methods: inspection, analysis, demonstration or test.

For the purposes of categorizing functional requirements for the VSL & QW subsystems, the following functional systems have been defined:

- ***Variable Speed Limit (VSL) Display System*** – Inclusive of the field devices that will be displaying the speed limits to passing motorists.
- ***Queue Warning Display System*** – Inclusive of field devices (dynamic message signs) that will be utilized to display queue warning messages to passing motorists.
- ***Detection System*** – Inclusive of the field devices to be utilized to collect traffic data used to support the algorithms and processes utilized to determine the appropriate speeds and warning messages to post on VSL and Queue Warning Display devices respectively.
- ***Communication System***- Inclusive of the communications media and equipment necessary to transport data and messaging between ITS field devices and the RTMC.
- ***VSL and Queue Warning RTMC Software System*** – Inclusive of software requirements needed to support the display of variable speed limit and queue warning messages. PennDOT currently utilizes Q-Free's OpenTMS software to support most ITS device management functions within the RTMC. The requirements developed under this section are intended to be agnostic to the OpenTMS software, i.e. they could be utilized to develop new or modify existing OpenTMS software modules, or be utilized as the basis for procuring and new VSL and Queue Warning support software entirely.

4.1 Primary Stakeholder

4.1.1 PennDOT

System: ***Variable Speed Limit (VSL) Display System***
This system shall:

- Meet all MUTCD requirements for speed limit display signage and legibility.
- Display the current speed limit to drivers.
- Support upcoming traffic control needs related to I-76 widening to accommodate future part-time shoulder use.
- Utilize LED display technology.
- Support installation on either new pedestal or existing ITS and sign structures.
- Support co-location with existing ITS devices.
- Receive commands from the RTMC central software which establishes the prevailing speed limit.
- Collect and report to the RTMC central software, the operational status of the VSL display system equipment including the following:
    - Communications Status
    - Device Status
    - Any device or pixel errors
    - Current message displayed on sign
- Monitor and report faults to the RTMC central software in accordance with NTCIP requirements.
- Provide the capability to share or restrict any and all device management functions with PennDOT or other networks.
- Support communications via fiber and Ethernet media.

System: ***Queue Warning Display System***
The system shall:

- Meet all MUTCD requirements for dynamic message signing and legibility.
- Display recognizable queue warning and other warning messages to motorists.
- Support all dynamic message signing performance requirements included in PennDOT Standard Specifications (Publication 408, Section 1230) for Dynamic Message Signs.
- Support upcoming traffic control needs related to I-76 widening to accommodate future part-time shoulder use.
- Receive commands from the RTMC central software.
- Collect and report to the RTMC central software, the operational status of the display system equipment including the following:
    - Communications Status
    - Device Status
    - Any device or pixel errors
    - Current message displayed on sign
- Interface with the Open TMS DMS display module so that messages unrelated to automated queue warnings can be posted to Queue Warning Display Signs.
- Monitor and report faults to the RTMC central software in accordance with NTCIP requirements.

- Provide the capability to share or restrict any and all device management functions with PennDOT or other networks.
- Support communications via fiber and Ethernet media.

System: ***Detection System***
This system shall:

- Monitor traffic and environmental conditions along the roadway including the following:
    - Vehicle speed
    - Vehicle occupancy
    - Vehicle throughput (volume)
    - Roadway condition including snow, ice, rain, etc.
- Support the detection of real-time queuing including stopped vehicles and slowing traffic.
- Provide real-time data to the RTMC Software System.
- Collect and transport data in a timely and accurate manner as necessary to support VSL and QW algorithms.
- Monitor and report faults to the RTMC central software in accordance with NTCIP requirements.
- Provide the capability to share or restrict any and all device management functions with PennDOT or other networks.
- Support communications via fiber and Ethernet media.

System: ***Communications System***
This system shall:

- Provide high-speed communications between field devices and the RTMC.
- Provide redundancy, such that the failure of individual communications devices or links does not result in the failure of the overall system.
- Integrate into the existing I-76 ITS communications network.
- Facilitate the distribution of vehicle detection, messaging, and speed limit data to external stakeholders.

System: ***VSL and Queue Detection RTMC Software System***
This system shall:

- Develop an algorithm to variably modify speed limits along the corridor based on the following criteria:
    - Current spot speed at VSL device locations as well as downstream slowdowns or building queues.
    - Prevailing travel times throughout the corridor.
    - Incident or event information entered by RTMC operators.
    - A calculation of the speed limit at which vehicle throughput is optimized both at VSL locations as well as along the corridor.
    - A consideration of roadway geometry, site distance, and grade at individual VSL locations.
    - Historic traffic patterns during a given time and day of the week for predictive purposes.

- Support the use of weather condition information to generate appropriate speed limits (potential future enhancement based on software vendor input).
- Support user-prompted speed limit modification.
- Define and support rules such that speed limits cannot be automatically or manually modified such that they conflict with prevailing MUTCD or Commonwealth of Pennsylvania guidelines.
- Display current speed limits on both a map and list view.
- Support the provision of real-time and archival speed limit information to Pennsylvania State Police through a direct data feed or by providing user credentials to PSP officers.
- Record and archive historical speed limit data.
- Develop an algorithm to variably generate queue detection alerts utilizing vehicle volume, speed, and occupancy data collected from field detection devices as well as incident data entered into OpenTMS and RCRS by RTMC operators.
- Generate alarms as queues are automatically detected.
- Provide the ability to visually display the limits of roadway queuing on a map of the corridor.
- Support automated posting and clearing of queue warning related messages to DMS based on prevailing traffic conditions.
- Support the manual posting of queue warning as well as other incident and event related messages (including automated travel times) to DMS.
- Support developing a hierarchy for queue warning related messaging.
- Contain a queue warning message library.
- Archive historical queue warning display messages.
- Provide real-time and historical queue and message data to external stakeholders.

4.2 Secondary Stakeholders

4.2.1 City of Philadelphia

System: ***Variable Speed Limit (VSL) Display System***
This system shall:

- Allow for the viewing of current speed limit data at the City of Philadelphia TOC.
- Provide sufficient warning along intersecting roadways within the City of Philadelphia that variable speed limits are in effect.

System: ***Queue Warning Display System***
The system shall:

- Allow for the viewing of queuing along the I-76 corridor from the City of Philadelphia TOC.

System: ***Communications System***
This system shall:

- Support high-speed communications between the PennDOT RTMC and the City TOC.

System: ***VSL and Queue Detection RTMC Software System***
This system shall:

- Support the transmission of VSL and QW related data and alerts between the PennDOT RTMC and City TOC.

4.2.2 Delaware Valley Regional Planning Commission (DVRPC)

System: ***Detection System***
This system shall:

- Collect and provide data to support further modeling and corridor planning efforts along I-76.
- Provide data to be utilized to determine effects of VSL and QW on harmonizing vehicle flow and reducing accidents along the corridor.

System: ***VSL and Queue Detection RTMC Software System***
This system shall:

- Support the transmission of VSL and QW related data to regional stakeholders.
- Support the integration of VSL and QW data and alerts into RIMIS.

4.2.3 Federal Highway Administration (FHWA)

System: ***Variable Speed Limit (VSL) Display System***
This system shall:

- Meet all MUTCD requirements for speed limit display signage and legibility.

System: ***Queue Warning Display System***
The system shall:

- Meet all MUTCD requirements for changeable message sign display and legibility.

4.2.4 Montgomery County

System: ***Detection System***
This system shall:

- Collect and provide queuing and incident data to support county 911 operations.
- Provide data to be utilized to determine effects of VSL on mobility and throughput throughout the I-76 corridor.

System: ***VSL and Queue Detection RTMC Software System***
This system shall:

- Support the transmission of VSL and QW related data to regional stakeholders.

4.2.5 Local Municipalities

System: ***Detection System***
This system shall:

- Collect and provide queuing and incident data to support municipal response.

System: ***Communications System***
This system shall:

- Support continued provision of center-to-center communications links to municipalities throughout the corridor.

System: ***VSL and Queue Detection RTMC Software System***
This system shall:

- Support the transmission of VSL and QW related data to regional stakeholders.

4.2.6 Pennsylvania State Police (PSP)

System: ***Variable Speed Limit (VSL) Display System***
This system shall:

- Allow for the viewing of current speed limit data by PSP within their vehicles as well as at Troop K Headquarters.

System: ***Queue Warning Display System***
The system shall:

- Allow for the viewing of queuing along the I-76 corridor from Troop K Headquarters.

System: ***Communications System***
This system shall:

- Support high-speed communications between the PennDOT RTMC and the PSP.

System: ***VSL and Queue Detection RTMC Software System***
This system shall:

- Support monitoring and operations of the VSL module by PSP from within the RTMC or remotely from Troop K or PSP Headquarters in Harrisburg.

4.2.7 Southeastern Pennsylvania Regional Transportation Authority

System: ***Queue Warning Display System***
The system shall:

- Allow for the posting of SEPTA related information to DMS.

System: ***Detection System***
This system shall:

- Collect and provide queuing and incident data to support SEPTA bus, high-speed line, and regional rail operations.

System: ***Communications System***
This system shall:

- Support continued provision of center-to-center communications.

System: ***VSL and Queue Detection RTMC Software System***
This system shall:

- Support the transmission of VSL and QW related data to regional stakeholders.

4.2.8 Traveling Public

System: ***Variable Speed Limit (VSL) Display System***
This system shall:

- Provide motorists with en-route traveler information to assist in safely traveling the I-76 corridor.

System: ***Queue Warning Display System***
The system shall:

- Provide motorists with en-route traveler information to assist in safely traveling the I-76 corridor.
- Provide motorists with en-route traveler information to better support route choice decisions.
- Display advisory messages including AMBER Alerts.

System: ***Detection System***
This system shall:

- Collect and provide queuing and incident data to support traffic operations along the I-76 corridor
- Provide speed limit and queuing data to third party traffic information providers (HERE, Waze, etc.).

System: ***VSL and Queue Detection RTMC Software System***
This system shall:

- Support the posting of speed limit and queue warning information to PennDOT website and mobile applications.

5. ITS Device Locations and Preliminary Design Methodology

The general design approach to locating field devices is to provide full coverage for the project limits. The location of the devices is driven by a set of requirements for each subsystem. The requirements do not dictate the design, but they do establish a standard for the design.

Requirements for VSL devices are driven by both the FHWA and PennDOT requirements for posting and modifying speed limits, as well as the operational needs for PennDOT to be able to reduce speed limits from speeds as high as 55 mph to as low as allowable over a short, but reasonable distance. This resulted in overall VSL spacing on the order of every ½ mile in each direction along the corridor.

The locations for the DMS devices to support queue warnings are driven by the needs of motorists and rear-end crash data along the corridor. These are locations approaching segments where rear-end crash data indicated rates over 2x greater than the statewide average. The primary function of the DMS is to provide traveler information regarding upcoming queues as well as providing additional routing or event information when traffic is flowing smoothly.

The requirements also include coverage requirements for vehicle detection to support both VSL & QW algorithms. The preliminary design includes the use of existing point-based remote traffic microwave sensors (RTMS) owned by PennDOT supplemented with additional RTMS sites owned by HERE and proposed to be taken over by the Department. Combined, these devices provide per-lane speed, volume, and occupancy data at approximate ½ mile increments along the corridor. Point detection data can also be supplemented by probe based data collected by E-Z Pass tag readers as well as that provided by INRIX, both having full coverage along I-76.

One general consideration given to the placement of new ITS devices for VSL and QW display devices was the upcoming I-76 Integrated Corridor Management Project, which will further investigate the widening of I-76 EB/WB between the Pennsylvania Turnpike and I-476 as well as I-76 WB between US 1 and Belmont Avenue to accommodate part-time shoulder use. Where devices were to be placed on new structures, care was given to ensure that they would be located outside of the anticipated 36-foot cross section of the improved roadway in each direction. Devices co-located with existing devices, or enhancements to existing devices such as HERE RTMS detectors were not given these considerations as their replacement can be coordinated into upcoming part-time shoulder use work.

In the sections that follow, the proposed locations for VSL signs, DMS, and vehicle detection are documented, with explanations of how these locations satisfy the coverage requirements and fall within the project scope. An overall layout of ITS devices locations to support VSL and QW along I-76 within the project limits in included in **Appendix A**.

5.1 Variable Speed Limit Display Devices

The variable speed limit design is inclusive of the location of VSL display devices approximately every ½ mile in both directions along I-76 as well as on major ramps entering the expressway, such as the EB ramp from US 202/US 422 to I-76 EB. The ½ mile spacing goal was determined to meet the requirements of utilizing the VSLs as both a speed harmonization and incident/weather safety device. In addition, VSLs were located as close to on-ramps as possible (sometimes including additional devices within the ½ spacing) in order to provide speed limit information to motorists as soon as they

enter the roadway. At the ½ mile spacing, PennDOT would have the ability to take the prevailing speed limit down from 55 mph to 35 mph safely over the span of approximately 1 mile (utilizing two concurrent devices at a reduction of 10 mph per device).

Within the ½ mile general guideline, efforts were made to co-locate VSL display devices with existing ITS devices as much as possible to economize communications and electrical services as well as provide a mechanism for mounting the VSL without needing an additional pedestal. In addition, it was assumed during the preliminary design that VSL devices could utilize existing ITS cabinets for VSL controller equipment. PennDOT CCTV camera and vehicle detection devices along the corridor have adequate available space within existing cabinets to accommodate any additional VSL equipment that would be needed to control the device.

VSL devices themselves will be MUTCD compliant static speed limit signs (48”x60”) with two-character LED display devices cut out to provide the speed limit information. Where available, it is intended that VSL devices be mounted to existing ITS or sign structures. For stand-along locations, the preliminary design includes a pedestal mounted sign. For both applications, it is recommended that the sign be mounted a minimum of seven (7) feet in height to the bottom of the sign in order to maximize visibility. Areas where the roadway footprint is sufficiently wide have been allocated two VSL devices, one on each side of the roadway in order to ensure visibility.

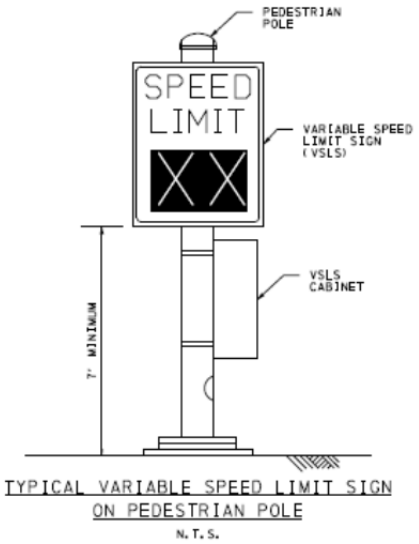


Figure 5: Typical VSL Pedestal Mount

5.2 Queue Detection System Display Devices

The current design proposes utilizing arterial-size DMS to display queue warning messages to passing motorists. Messages in the concept of operations were developed utilizing a basis of 10x18” characters in three (3) rows. DMS structure design and specifications will size signs appropriately to meet this requirement. DMS provide a valuable means of communicating traveler information to motorists while en-route. They allow operators in the RTMC to convey information to motorists related to congestion, incidents, AMBER alerts, weather, and road closures. DMS are usually located in advance of major interchanges, but in the case of the Queue Warning Displays, they are being located in advance of the highway segments exhibiting rear-end crash rates of greater than 2x the statewide average.

In District 6-0, locations of DMS are coordinated with the placement of major route guidance signs to remain compliant with FHWA, PennDOT, and MUTCD sign placement standards. The requirements for sign visibility assume 30-degree cone of vision to the perpendicular axis to the sign for a distance of 600-1,000 feet from the sign. While, the selection of locations for DMS along I-76 was driven by the accident data, DMS will be specified utilizing PennDOT Publication 408 standards which will ensure that they will be able to post any message including travel times.

It is anticipated that DMS locations installed under this project may subsequently be relocated to full span sign gantries when the corridor is upgraded to accommodate part-time shoulder use as well as lane use control. As such, it is recommended that the initial deployment of these signs under this project utilize Type-A sign supports, which are approved for use for smaller DMS under Department ITS standards. Even if not subsequently moved, the Type-A mounting will be sufficient to provide a clear field of view for motorists.

Each DMS device will include a new power and communication supply, new ITS node cabinet, and new Type-A sign structure, as well as the conduit and cable infrastructure to support the device. The sign structures will utilize break-away posts, which negates the requirement for new guiderail, however most locations will be installed behind existing barrier or guiderail, and thus be fully protected.

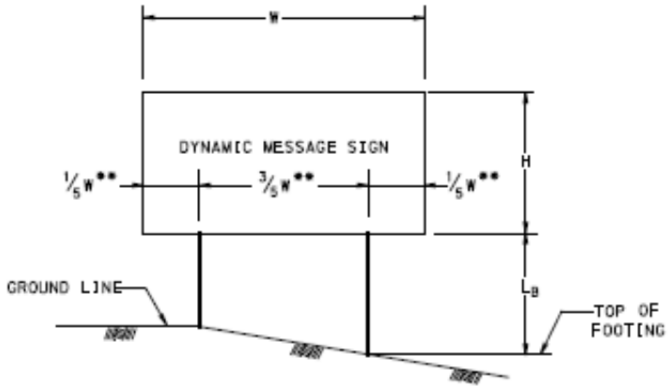


Figure 6: Type-A DMS Mounting

5.3 Vehicle Detection Devices

The desire to utilize VSL devices to maximize vehicle throughput along the corridor as a congestion management tool, requires that accurate volume data be collected throughout the corridor limits. Of the three (3) detection technologies currently available to support VSL and QW (RTMS, INRIX, E-ZPass Probe), only RTMS data provides complete speed volume and occupancy data. Probe data is insufficient because it cannot provide accurate volume counts, and E-ZPass data is spread out over too wide of an area to support queue detection and monitoring. However, both sets of data can and should be utilized to provide supplemental data in implementing VSL and queue detection algorithms in the RTMC central software system.

There are currently two (2) sources of RTMS data along I-76 within the project limits. One is the PennDOT-owned detection devices installed under the S.R. 0076, Section ITS project, and the other is legacy devices owned by HERE (formally traffic.com, and here-to-for referred to as traffic.com detectors). PennDOT has the opportunity to assume ownership of these devices, and it is recommended that this occur in order to support both VSL & QW data requirements.

Existing Traffic.com detector locations are solar powered and are not directly connected into the PennDOT fiber communications network. The devices are mounted to 40-foot steel poles and were installed by Traffic.com within PennDOT right-of-way in the early 2000s. At these locations, it is recommended that each detection device be replaced with two (2) new RTMS detectors meeting PennDOT ITS standards (to cover both directions of I-76). Two (2) detection devices will ensure that individual detectors can be mounted such that they can see over the median barrier into the opposing direction of traffic. In addition, each location will include a hard-wired power source, fiber communications drop from the main backbone, new ITS node cabinet, and conduit/cabling to support device functionality. It is being assumed for the purpose of preliminary design that existing detector structures can be utilized.

There are two (2) Traffic.com detector locations indicated on the preliminary ITS plans that show existing detectors to be abandoned. They are located WB near the Pennsylvania Turnpike Toll Plaza,

and EB at mile marker 334.7. The WB device near the toll plaza would provide redundant data to the device located at mile marker 326.5. The device at mile marker 334.7 is located within 1/10th of a mile of an existing DMS location where a new detector can be mounted and negate the need for a new dedicated power and communications service.

5.4 Proposed ITS Device Locations

The following **Tables 1 and 2** provide an overview of ITS locations broken up into the EB and WB direction by mile-post. Each milepost entry indicates whether a VSL, DMS or upgraded Traffic.com detector is included as well as general notes regarding the location or scope of work. In total, the project preliminary design includes the installation of 61 new VSL signs, eight (8) DMS, and the retrofitting/integration of 18 Traffic.com detection locations.

Table 1: Proposed ITS Device Location EB I-76

Mile Marker	VSL	Traffic.com	DMS	Notes
326.95	1	1	1	At existing Traffic.com detector. DMS located 300' to the west of VSL. Provide new structure, ITS cabinet, and power/communications supply. Provide new vehicle detection device.
327.45	1			At existing speed limit sign. Provide new pedestal, ITS cabinet, and power/communications supply.
SR 202 Ramp	1			At existing TR202_13N. Utilize existing power/communications.
328.2	1			At existing CM700. Utilize existing power/communications.
328.6	1			At existing overhead DMS 76E_02. Utilize existing power/communications.
329.15	1			At existing CM701. Utilize existing power/communications.
330.25	1			At existing CM705. Utilize existing power/communications.
330.45	1		1	Install VSL on existing sign structure 250' east of proposed DMS. Provide new ITS cabinet, power and communications supply.
331	1			At existing CM 706. Utilize existing power/communications. Include new vehicle detection.
331.7	1	1		Upgrade existing traffic.com in median to cover EB and WB traffic with new detection devices. Install EB VSL off of shoulder. Provide new ITS cabinets, power and communications supplies.
331.9	1		1	Install at existing overhead sign structure (no static signing in EB direction). Provide new ITS cabinet, power and communications supply.
332.6	1			At existing CM709. Utilize existing power/communications.
333.2	1	1	1	At existing Traffic.com detector. Provide new ITS cabinet, power, and communications supply. Provide new detection devices.

Mile Marker	VSL	Traffic.com	DMS	Notes
333.85	1			Install new VSL pedestal. Provide new ITS cabinet, power/communications supply.
334.3	1			At existing CM 712. Utilize existing power/communications.
334.8	1			Remove Traffic.com detector at 334.7. Install new detector & VSL at existing DMS location.
335.15	1			At existing CM713. Utilize existing power/communications.
335.6	1			At existing RTMS DA706. Utilize existing power/communications.
336	1			At existing CM714. Utilize existing power/communications.
336.53	1			Across from existing CM715. Provide new pedestal. Provide new power/communications supply.
337.1			1	Locate behind barrier. Coordinate ROW limits with railroad. Provide new DMS structure and cabinet. Provide new power/communications supply.
337.3	1	1		At existing Traffic.com detector. Provide new power/communications supply. Provide new vehicle detection device.
337.8	1			On Exit 338 sign structure. Provide new ITS cabinet, power and communications supply.
338.2	1			At existing overhead sign structure. Remove traffic.com detector, add new detection to sign structure to cover EB traffic. Provide new ITS cabinet, power and communications supply.
338.5	1			On Exit 340A sign structure. Provide new ITS cabinet, power and communications supply.
339	1			Install new pedestal VSL support. Provide new ITS cabinet, power/communications supply.
339.5	1			On Exit 340B sign structure, next to existing CCTV. Tap power/communications off of existing CCTV.
339.9	1			On left side of Exit 340B overhead sign structure, co-located with existing TR
340.3	2	1		VSL on both sides of roadway. Install new pedestal, ITS cabinet, power/communications supply. Provide new vehicle detection device.
TOTAL	**29**	**5**	**5**	

Table 2: Proposed ITS Device Location WB I-76

Mile Marker	VSL	Traffic.com	DMS	Notes
340.25	1			On left side of Exit 340B overhead sign structure. Provide new power/communications. Provide new ITS cabinet. Provide new vehicle detection.
340.05	1			On Exit 340A sign structure. Provide new power/communications. Provide new ITS cabinet.
340			1	Install new DMS and DMS Structure. Provide new power/communications. Provide new ITS cabinet.
339.8	2			On both sides of Exit 339 / 340A overhead sign structure, co-located with TR 7607. Utilize existing power/communications.
339.7		1		Replace detection device, provide new power/communications. Provide new ITS cabinet.
339.2	1	1		At existing Traffic.com detector. Replace detection device, provide new power/communications. Provide new ITS cabinet. Provide new vehicle detection device.
338.6	1			At existing CM 719. Utilize existing power/communications.
338.2			1	In median. Provide new power/communications. Provide new ITS cabinet.
338.15	1			On Exit 338 overhead sign structure. Provide new power/communications. Provide new ITS cabinet.
337.6	1			On Exit 337 sign structure. Provide new power/communications. Provide new ITS cabinet.
337.2	1	1		At existing CM-717. Utilize existing power/communications. Provide new detection device.
336.7	1			At existing CM 716. Utilize existing power/communications.
336.35	1	1		At existing Traffic.com detector. Replace detection device, provide new power/communications. Provide new ITS cabinet.
335.8	1			Just beyond maintenance yard. Provide new pedestal, ITS cabinet, power and communications supply.
335.15	1			Across from existing CM 713. Provide new pedestal, ITS cabinet, power and communications supply.
334.8	1			At existing DMS 76W_03. Utilize existing power/communications.
334.2	1	1		Replace detection device, provide new power/communications. Provide new ITS cabinet.
333.8	1			On Exit 332 sign structure, co-located with CM711. Utilize existing power/communications.
333.4	1		1	At existing CM 710. Provide new power supply to DMS. Utilize existing communications. Provide new ITS cabinet.

Mile Marker	VSL	Traffic.com	DMS	Notes
332.8	1			On Exit 331A/B overhead sign structure. Provide new power/communications. Provide new ITS cabinet.
332.35	1			Install new pedestal VSL support, ITS cabinet, power/communications.
332	1			At existing CM708. Utilize existing power/communications
331.7	1			At existing CM707. Utilize existing power/communications.
331.35	1			Install new pedestal VSL support, ITS cabinet, power/communications.
331.1	1			Across from existing CM706. Install new pedestal VSL support, ITS cabinet, power/communications.
330.55	1			At existing CM 705. Utilize existing power/communications.
330	1	1		Replace detection device, provide new power/communications. Provide new ITS cabinet.
329.5	1			On Exit 328/327 sign structure, co-located with existing CCTV & TR. Utilize existing power/communications.
329.1	1			Across from existing CM 701. Install new pedestal VSL support, ITS cabinet, power/communications.
328.6	1			At existing DMS 76W_01. Utilize existing power/communications.
328.1	1			On Exit 327/328A sign structure. Install new ITS cabinet, power/communications.
327.7	1			On Exit 328B-A/327 overhead sign structure. Install new ITS cabinet, power/communications.
327.2	2			On both sides of Exit 327/328A overhead sign structure. Install new ITS cabinet, power/communications.
TOTAL	**32**	**6**	**3**	

6. Communications Plan

The purpose of this communications plan is to present a conceptual design for the ITS field device subsystems and the ITS communication subsystem for the I-76 VSL & QW project. The designed ITS system will meet and fulfill the goals and requirements set in the ConOps and the Functional Requirements. The design of the communications system will follow PennDOT standard practices and integrate into the District's regional fiber optic communications network.

6.1 Assessment of Available Communications Media

This section evaluates the telecommunication alternatives available for transferring data between the PennDOT District 6-0 RTMC and the ITS field devices proposed to be installed along the I-76 corridor. Currently, PennDOT is using fiber optic cable, leased T-1 lines, cellular wireless and dial-up telephone lines for communication purposes; however, the District has been migrating to a predominantly fiber based system as new projects are being developed and coming online. Fiber based Open Transport Network (OTN) with Ethernet technology is the preferred alternative that coincides with PennDOT's long term regional ITS plans and is also the existing communications media deployed throughout the I-76 corridor. **Figure 7**, below shows an overview of the diverse ring network topology currently utilized by PennDOT District 6-0.

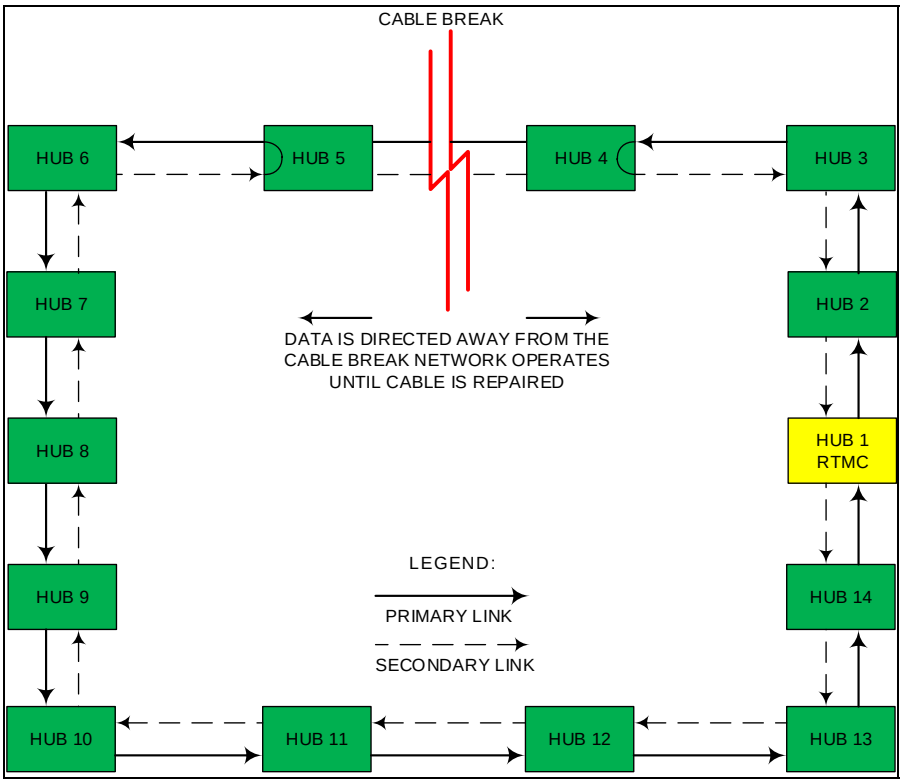


Figure 7: Diverse Communications Network Topology

The redundant fiber-ring based OTN network currently in place between US 202 and US 1 along I-76 is the most logical communications alternative for connecting proposed vehicle detection, VSL and

QW display devices. Cellular and leased services are also a viable option, but do not provide the reliability and bandwidth of the existing PennDOT fiber network, and would include a recurring service cost for their use.

DMS, VSL, and vehicle detection devices are all relatively low-bandwidth (on the order of 10-100Kbps) and all commercially available devices meeting PennDOT standards support Ethernet communications. A field Ethernet ring currently exists along I-76 to support vehicle detection, DMS, and travel time reader devices between OTN network hubs. It is recommended that this ring be utilized to facilitate the communication of new devices back to the OTN hubs where they can be transferred into the field communications network ring.

6.2 Proposed Modifications

No fiber optic cable infrastructure currently exists between US 202 and the Pennsylvania Turnpike interchange on I-76. The preliminary design currently includes the extension of the 144 strand ITS backbone fiber from US 202 west to the first eastbound VSL located at mile marker 326.95. New junction boxes, conduit, splice enclosures, and field Ethernet network switches will be required at all ITS devices not co-located with an existing device.

Existing ITS network hubs 76-2, 76-3, 76-4, as well as the head end hub at the RTMC will need to be modified to accommodate additional ITS devices and bring them into the field-to-center communications network. It is not anticipated at this time that any substantial modifications will need to be made to either ITS field or RTMC communications networks in order to accommodate the additional ITS devices.

6.3 Integration Plan

The purpose of the Integration Plan is to define interface requirements and information exchanges with planned and existing systems and subsystems and the level of effort required to fully integrate the new elements with existing systems shall be established. The I-76 VSL & QW project is categorized according to its component devices and systems. This hierarchy is consistent with what is presented in the Communications Plan and details what will be required to fully incorporate the proposed elements of the new ITS with the existing hardware, software, and institutional structures that already exist in District 6-0.

Integration requirements are divided into ITS Device and ATMS Software Integration categories:

- Communications integration includes making sure all the communications equipment is properly configured, connected, and tested. This report assumes that communications integration will be developed as part of communications design and provided as a service to the interfaces being communicated.
- Software integration includes revisions to or creation of software to provide portions of the interfaces needed between entities in the system. It includes relatively simple tasks such as configuring software for a new device that is already supported, to complex tasks such as developing support for new kinds of devices and sharing data and control between agencies.

6.4 ITS Device Integration

All new ITS devices will be connected to either a new or existing fiber optic Ethernet network switch installed in an ITS node cabinet. Each switch will be daisy-chained with other network switches between ITS communications hubs to create an Ethernet loop topology, as indicated in **Figure 8**.

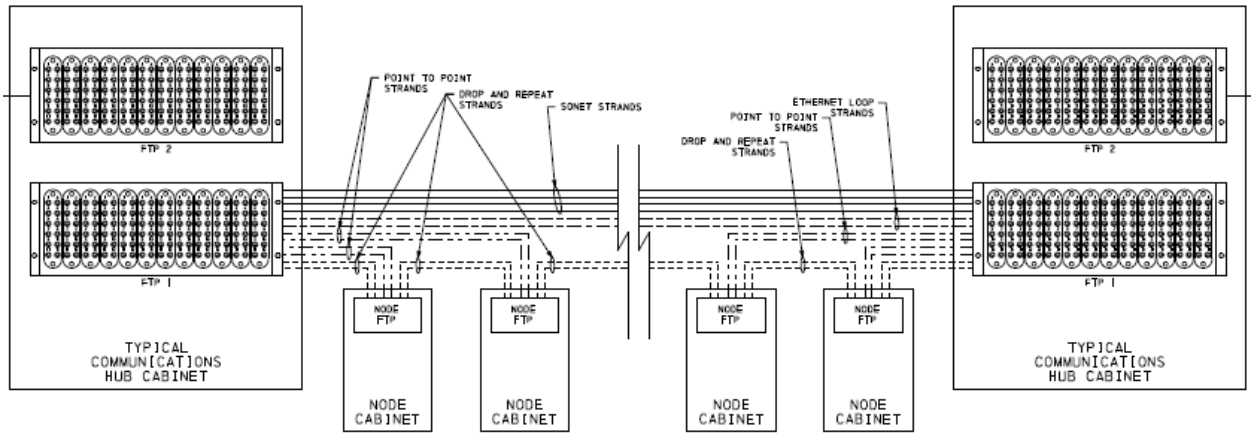


Figure 8: Ethernet Loop Communications Network Topology

The loop network topology allows for redundancy and resilience by creating dual paths for each ITS device to communicate in the event of a power or communications outage between hubs or at a specific ITS device location. A detailed communications network topology including splice diagrams and field-to-field/field-to-center data flows will be provided as part of the final ITS design.

6.5 ATMS Software Integration

PennDOT is currently in the process of rolling out their statewide ATMS Software (OpenTMS) throughout all PennDOT Districts. OpenTMS has been operational at District 6-0 for approximately one (1) year. OpenTMS, as it is currently configured with the RTMC, provides some functionality that can support VSL & QW along I-76, such as the collection of data from RTMS detection devices and the automated posting of message on DMS, but it does not provide any modules that specifically support strategies discussed in this report.

The ATMS software integration component of this project will need to include the following:

- Development of VSL and Queue Warning modules to support functional requirements.
- Development of algorithms to support the automated generation of alarms, messages, and speed limits.
- Integration of all devices into existing OpenTMS DMS and vehicle detection modules to ensure continuity of operations within the District TMC.
- Integrate VSL and QW with existing PennDOT systems such as RCRS.
- Integrate VSL and QW modules with Pennsylvania State Police Operations.

6.6 System Testing and Acceptance

It is recommended that PennDOT utilize the standard system testing and acceptance requirements in

Publication 408, however include the requirements for the factory testing of VSL devices as well as utilize a six-month operational test period and a two-year ITS support period due to the complexity of the integration required. In general, acceptance testing should take place in three (3) stages such that problems are identified corrected early on in the deployment process: preliminary/factory testing, site acceptance testing, and system acceptance testing. For each level of testing, a test plan should be developed based on the performance criteria, specifications, and requirements of the system's elements. Furthermore, all elements should be retested periodically after system upgrades or additions of new devices.

In addition, the field integration component of the overall project should include the complete on-site and systems acceptance testing process for existing PennDOT-owned RTMS detection devices. These devise were installed and commissioned approximately seven years ago and have since not been recalibrated.

7. Maintenance and Operations

7.1 Ongoing Maintenance Assessment

PennDOT Engineering District 6-0 will be the primary operator and maintainer of the VSL and QW devices. All ITS devices and systems will have to be included in the existing District ITS maintenance program. That includes and operational test period as part of device installation as well as an ongoing support period following construction. The durations for these periods range from 60-days to 6-months, and six-months to two-years respectively, but for a project of this complexity and considering the new technologies and systems that are going to be deployed, the longer durations are recommended.

Following the completion of the project's support period, the devices will be integrated into the District's existing ITS maintenance contract. Below is a high level analysis of the devices associated with the VSL and QW deployment project, their lifecycle and anticipated maintenance costs. Annual maintenance costs were derived from a previous review of ITS device lifecycle in District 6-0 as well as from the FHWA's 2010 Cost Elements Database.

Table 3: Maintenance Cost Estimate

Concept / Component	Lifecycle (Years)	Number of Devices	Annual Maintenance Cost per Device	Total Annual Maintenance Cost*
VSL	20	61	$500	$30,500
QW				
- Detection	10	30	$500	$15,000
- Signs	20	8	$2,000	$16,000
Communications				
- Fiber	25	2500 ft.		
- Equipment	15	41		
			Total	**$61,500**

*Not inclusive of replacement at the end of the lifecycle

7.2 Impacts to Ongoing Operations

Even though many of the functions of VSL and QW are intended to be automated, there will be a significant verification and asset management component to their operations which will place additional responsibilities on RTMC operators. For example, RTMC operators will need to visually verify that queuing is occurring following warnings from the central software system and make sure that VSL and Queue Warning devices are adequately responding to the prevailing conditions.

Close coordination will also be required with PSP to put policies and procedures in place for the provision of VSL data to law enforcement officers, the enforcement of VSL operations, and the storage of VSL data for further law enforcement use. A new workstation in the RTMC for PSP staff, was identified as an improvement concept in the I-76 ITS Enhancements Concept of Operations and would allow PSP staff to directly communicate with and dispatch officers in the field as conditions dictate. A secondary benefit will be enhanced coordination between RTMC operators and PSP staff.

It is envisioned that a dedicated PSP operator within the RTMC will also assist in expediting PSP response to incidents that occur throughout the District in addition to the I-76 corridor. The cost for PSP staff needs to be coordinated with PSP.

8. High-Level Cost Assessment

Table 4, below includes the high-level cost assessment for this project based on the preliminary design. It should be noted that these costs reflect the preliminary conceptual layout for the ITS components and systems integration, and includes a contingency to account for unforeseen conditions encountered as the design progresses. As further progress is made in design process and formal quantities are calculated, this estimate is subject to change and will be modified for each subsequent ITS design submission in greater detail.

Table 4: High-Level Cost Estimate

Work Item	Quantity	Unit Cost	Total Cost	Notes
Variable Speed Limit Display Device	61	$5,000.00	$305,000.00	
Queue Detection Display Device	8	$25,000.00	$200,000.00	Includes DMS and Type-A Structure
RTMS Vehicle Detector	30	$4,000.00	$120,000.00	Includes two detection devices at each traffic.com site and other locations indicated for additional detection coverage.
ITS Node Cabinet	41	$2,250.00	$92,250.00	Included at all new DMS and stand alone Vehicle Detection and VSL Devices
New ITS Power Service	41	$12,500.00	$512,500.00	Included at all new DMS and stand alone Vehicle Detection and VSL Devices
New ITS Communications Service	41	$7,500.00	$307,500.00	Included at all new DMS and stand alone Vehicle Detection and VSL Devices
Modification of Existing ITS Power Service	25	$4,500.00	$112,500.00	Included at all co-located VSL and vehicle detection devices
Modification of Existing ITS Communications Service	25	$3,000.00	$75,000.00	Included at all co-located VSL and vehicle detection devices
New I-76 Backbone Fiber (ft)	2500	$40.00	$100,000.00	New 144 strand fiber between US 202 and VSL-01EB. Includes conduit/junction boxes
Field Integration	1	$75,000.00	$75,000.00	
Software Integration	1	$200,000.00	$200,000.00	
Traffic Control	66	$5,000.00	$330,000.00	66 setups
E&S Control	4%	$103,400.00	$103,400.00	4% of total
Testing and Operational Support	80	$ 1,250.00	$100,000.00	105 individual devices
Mobilization	1	$134,420.00	$134,420.00	5% of total
Contingency	30%	$772,931.25	$846,846.00	30% for preliminary estimate
TOTAL ESTIMATED COST			**$3,614,416.00**	

9. System Procurement

It is recommended that the procurement and construction of the majority of elements for the VSL and QW project follow a traditional Design-Bid-Build process, as is customary for most ITS deployments. The consulting contract for the design of the improvements has already been procured and is underway. All VSL and QW field elements utilize proven and well known technologies, so their implementation is not anticipated to be overly complex. PennDOT has already deployed DMS and vehicle detection devices extensively throughout the District and employs a staff with prior ITS and operations experience.

Two (2) exceptions include the solicitation of a systems integrator and software vendor for the project. Being completely new systems within the RTMC that will rely on a significant amount of data processing and system automation, it is critical that the software component of the VSL and QW project be well defined through the final design phase. This will include close coordination with Q-Free, the existing ATMS software vendor, to determine their ability to meet the functional requirements outlined in this report. If not, then a formal set of software requirements will be developed to support the VSL and QW needs, and a separate software and integration contract can be procured independently or through the overall field construction project.

If Q-Free is able to meet all of the functional requirements to the satisfaction of the Department, it would be recommended that the development, testing, and integration of new software modules coincide with the final design of field and communications elements such that it can be in place as soon as field devices are ready for integration, minimizing any potential delays.

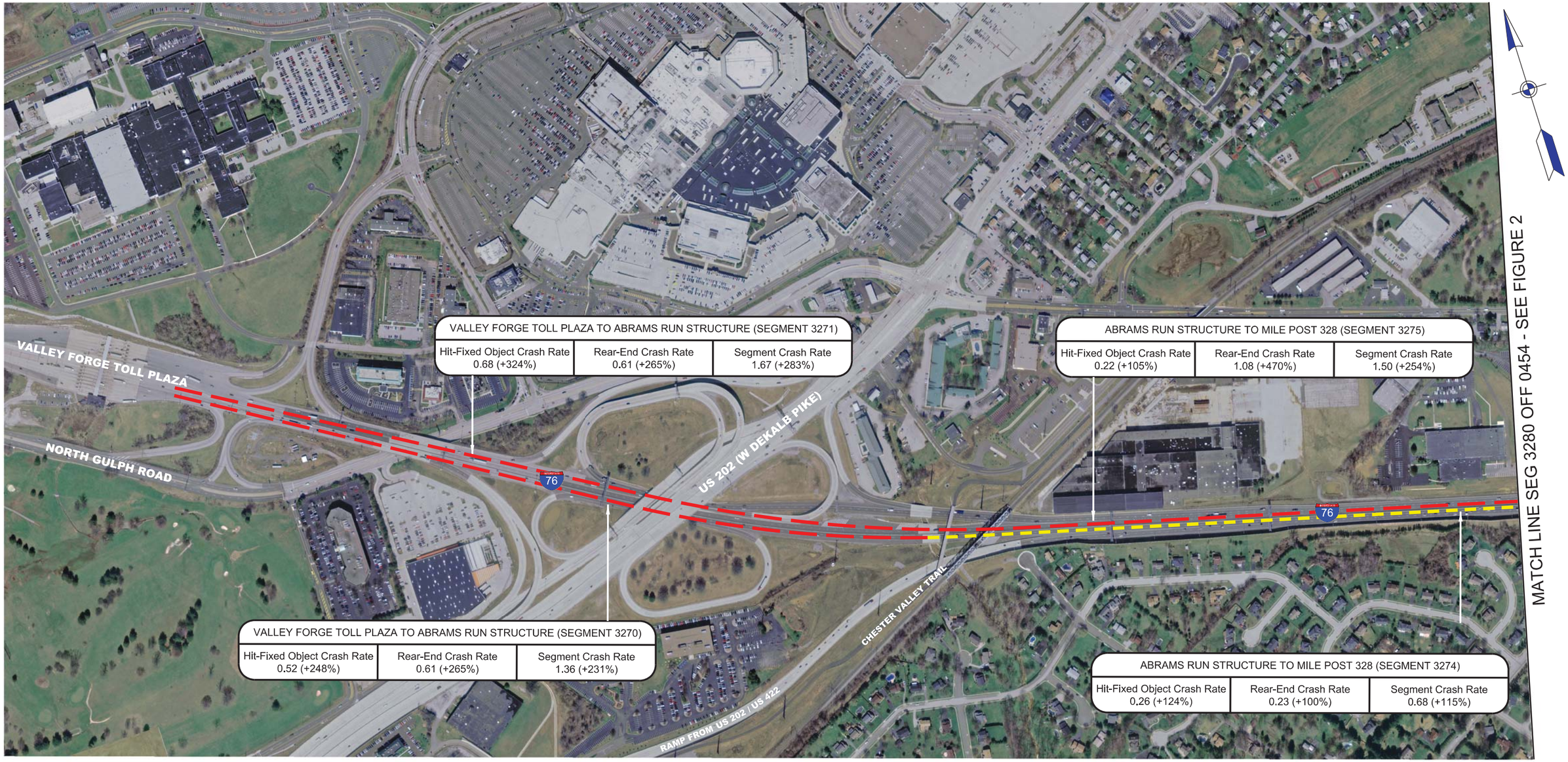
10. Referenced Documents

The following list of documents was used as supporting references and resources in developing this ConOps:

- American Highway Users Alliance, “Unclogging America’s Arteries: Prescriptions for Healthier Highways”, 2015.
- DVRPC, “Schuylkill Expressway Operational Research Model: Final Report”, 2012.
- FHWA, “Developing and Using a Concept of Operations in Transportation Management Systems”, 2005.
- FHWA, “Welcome to Active Transportation and Demand Management (Website)”, 2015.
- PennDOT (CH2M+Hill), “Draft Concept of Operations: Active Traffic Demand Management Implementation Plan”, 2013.
- PennDOT (Jacobs), “I-76 ITS Enhancements: Concept of Operations”, 2016.
- Texas A&M Transportation Institute, “Planning and Evaluating ATM Strategies”, 2015.

Appendix A:

Existing Crash Hotspots



LEGEND

- BELOW STATEWIDE AVERAGE CRASH RATE
- 1X - 2X ABOVE STATEWIDE AVERAGE CRASH RATE
- 2X OR ABOVE STATEWIDE AVERAGE CRASH RATE
- CONGESTION HOTSPOT
- EXISTING DMS (DYNAMIC MESSAGE SIGN)
- VARIABLE SPEED LIMITS
- DYNAMIC LANE ASSIGNMENT
- JUNCTION CONTROL
- PART-TIME SHOULDER USE
- RAMP METERING
- QUEUE DETECTION
- CONNECTED VEHICLE APPLICATIONS
- MULTI-MODAL / TRANSIT IMPROVEMENTS

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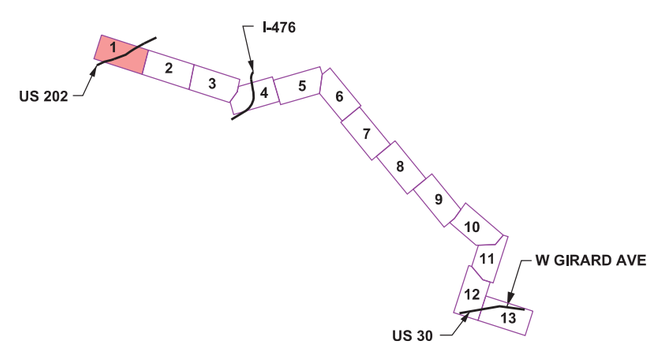

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PA Turnpike to US 1

EXISTING CRASH HOTSPOTS

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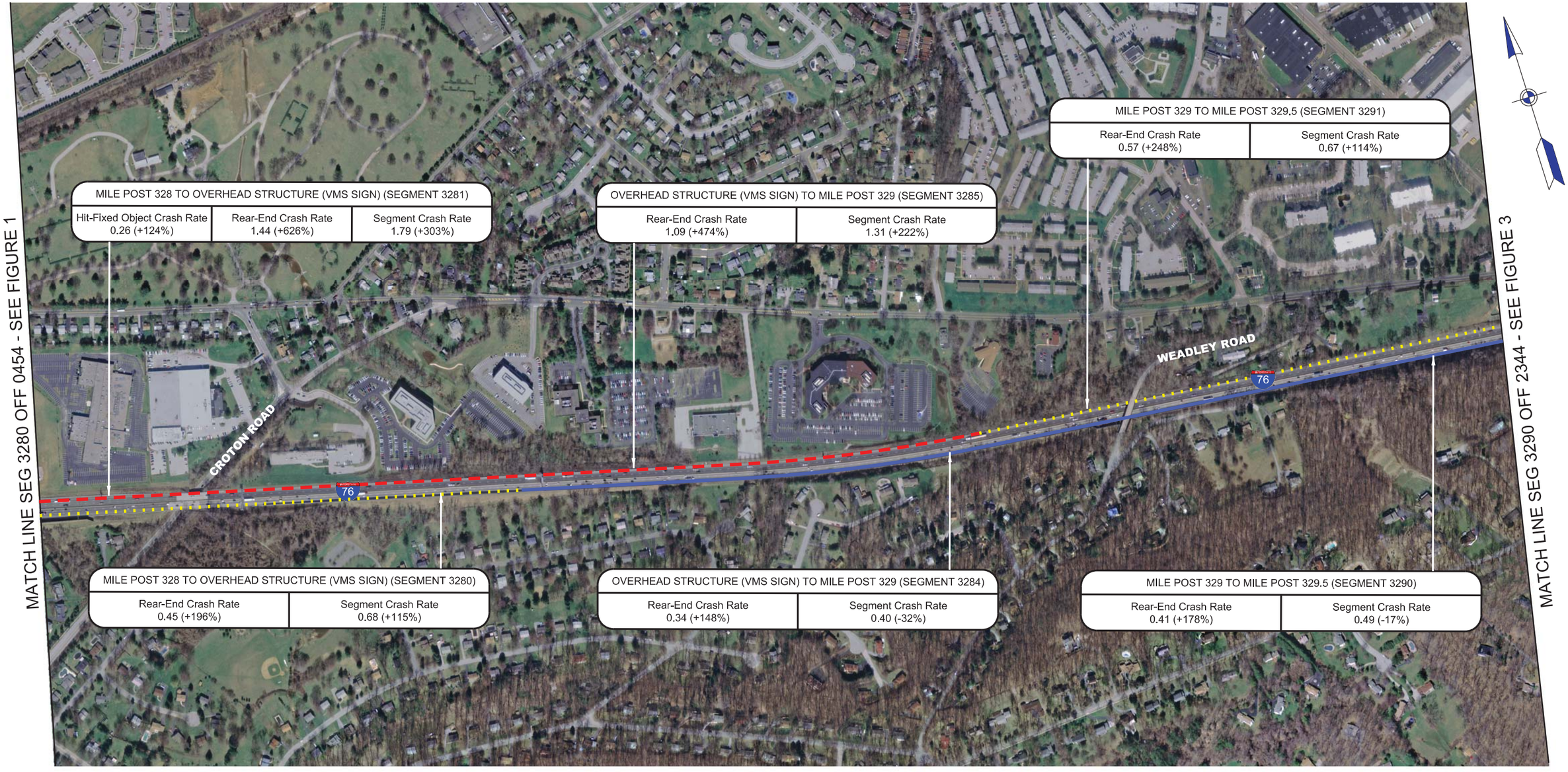
JAN 2017	FIGURE 1



LEGEND

- BELOW STATEWIDE AVERAGE CRASH RATE
- 1X - 2X ABOVE STATEWIDE AVERAGE CRASH RATE
- 2X OR ABOVE STATEWIDE AVERAGE CRASH RATE
- CONGESTION HOTSPOT
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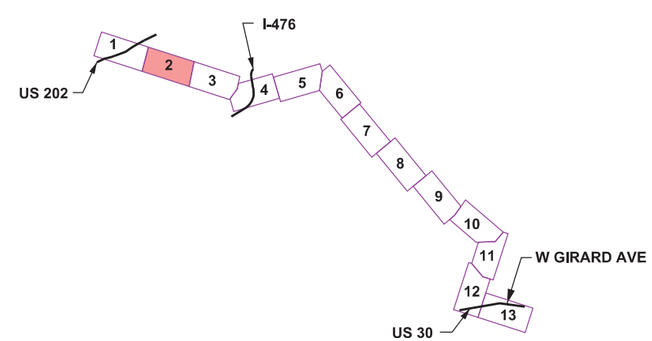

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I-76 ITS ENHANCEMENTS

PA Turnpike to US 1

EXISTING CRASH HOTSPOTS

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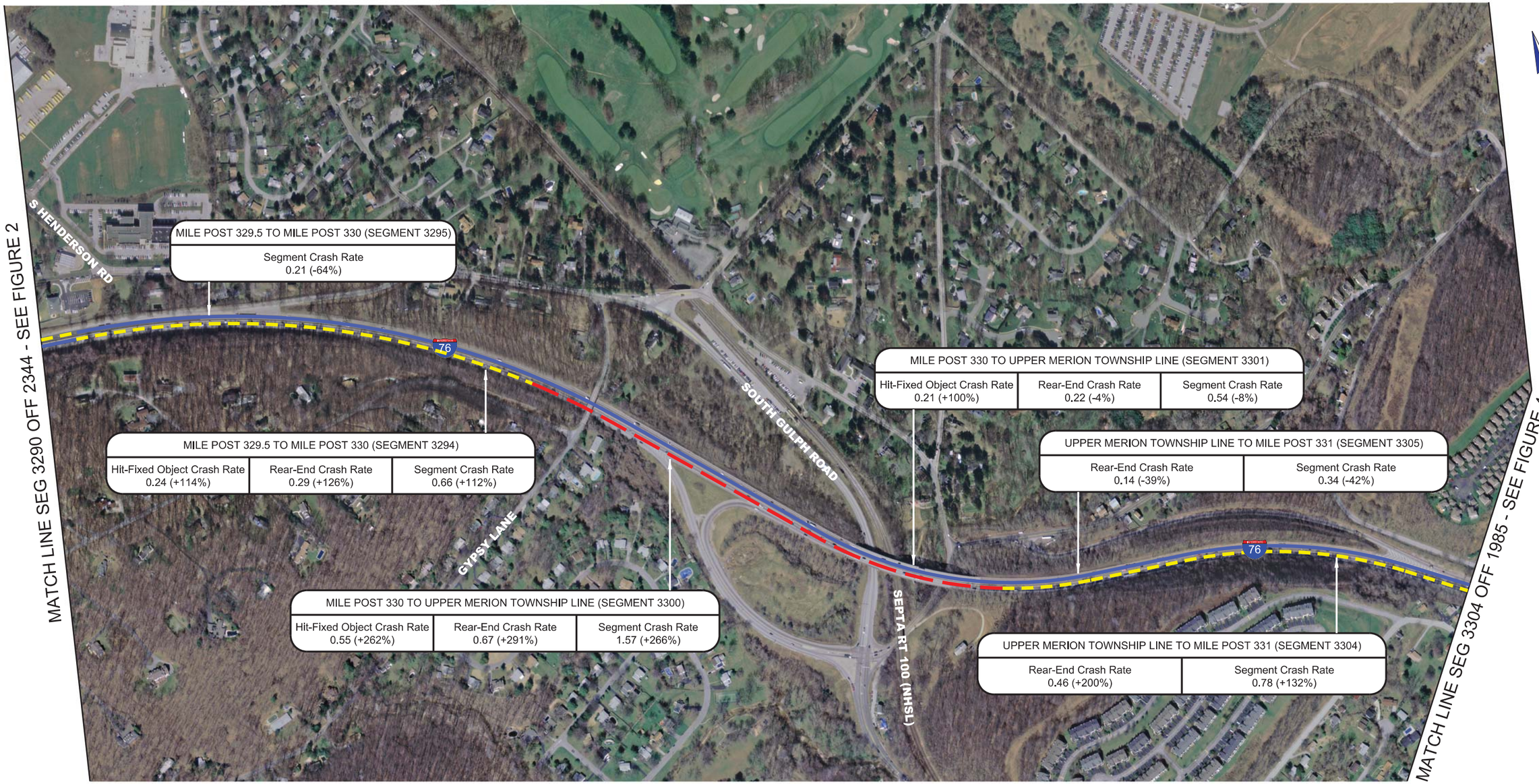
FIGURE 2



LEGEND

- BELOW STATEWIDE AVERAGE CRASH RATE
- 1X - 2X ABOVE STATEWIDE AVERAGE CRASH RATE
- 2X OR ABOVE STATEWIDE AVERAGE CRASH RATE
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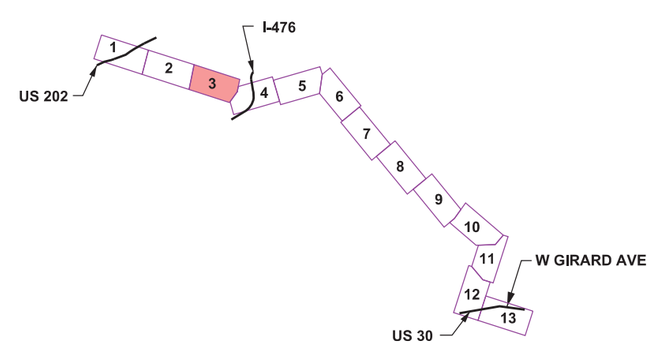

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PA Turnpike to US 1

EXISTING CRASH HOTSPOTS

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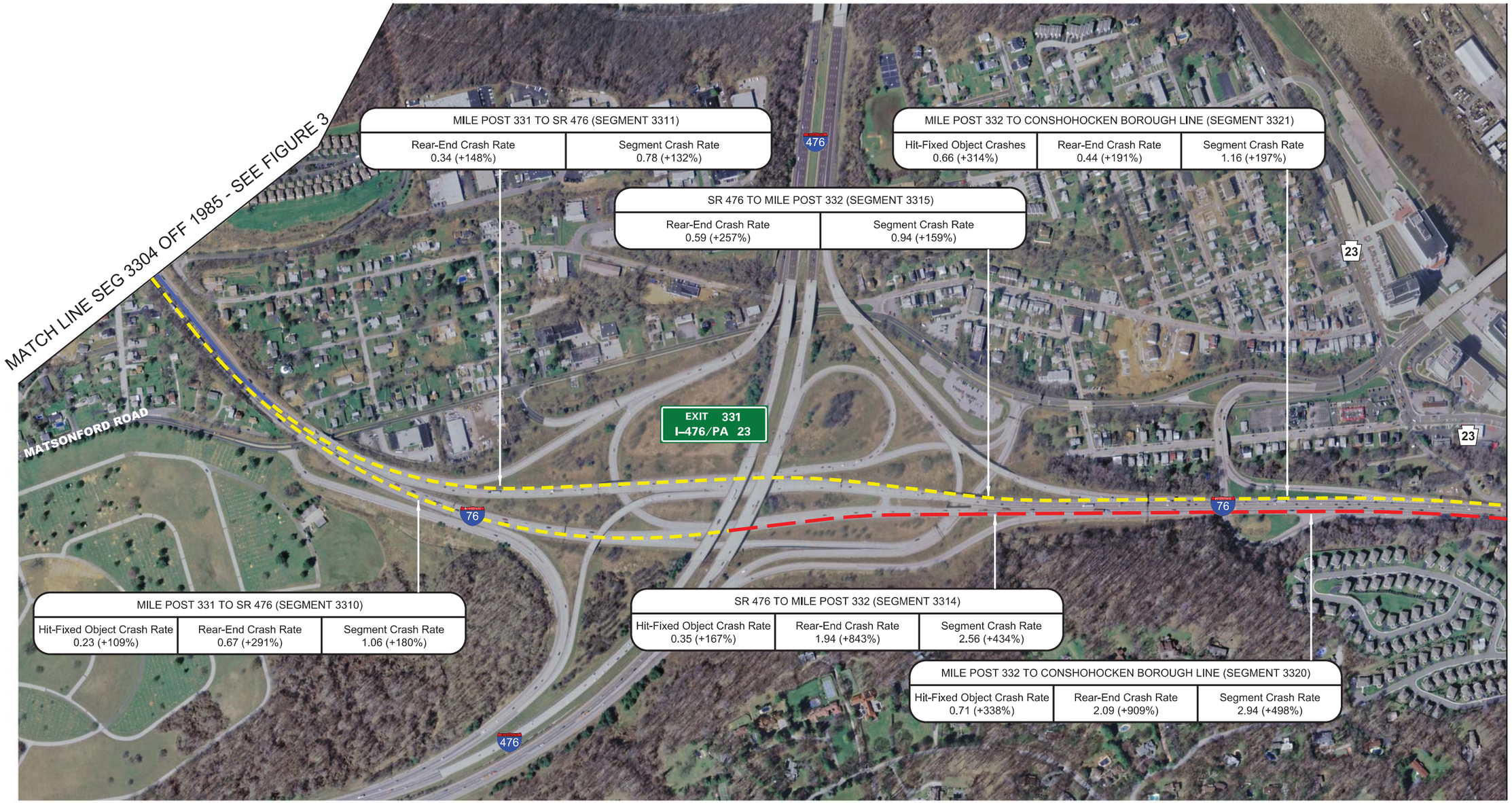
FIGURE 3



LEGEND

- BELOW STATEWIDE AVERAGE CRASH RATE
- 1X - 2X ABOVE STATEWIDE AVERAGE CRASH RATE
- 2X OR ABOVE STATEWIDE AVERAGE CRASH RATE
- CONGESTION HOTSPOT
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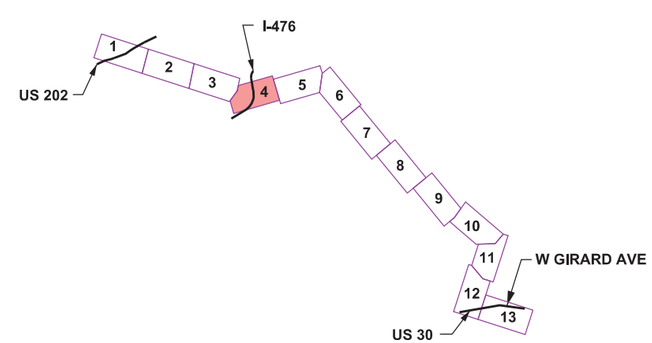

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PA Turnpike to US 1

EXISTING CRASH HOTSPOTS

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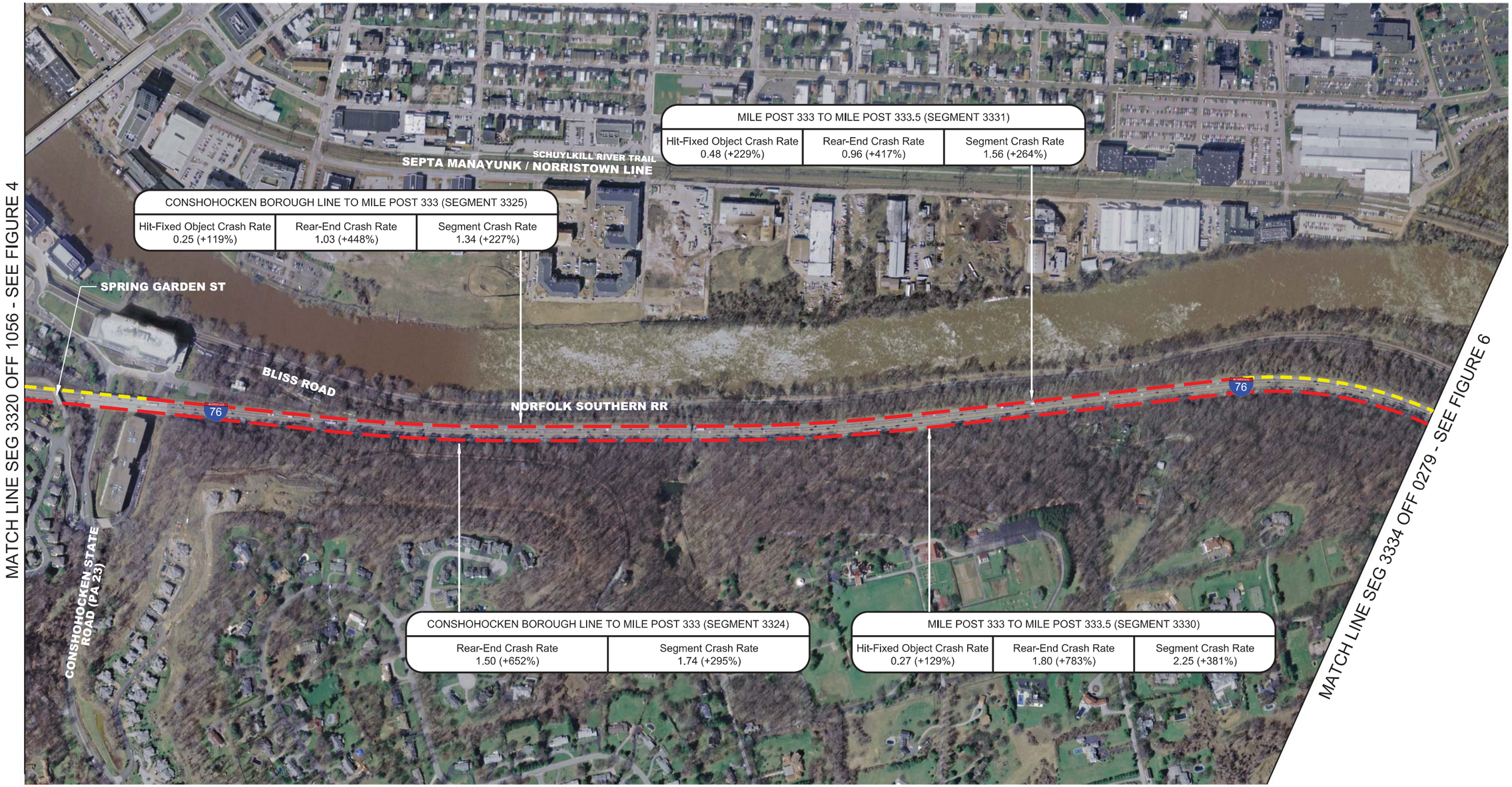
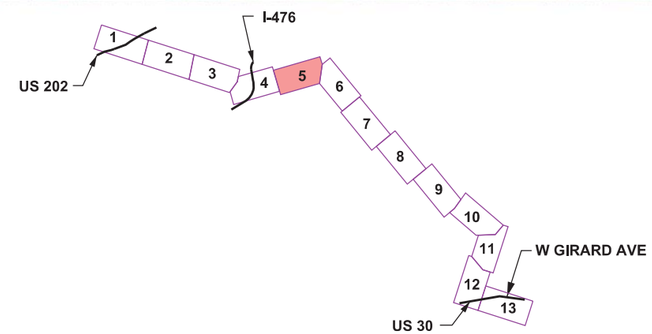
FIGURE 4





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LEGEND

- BELOW STATEWIDE AVERAGE CRASH RATE
- 1X - 2X ABOVE STATEWIDE AVERAGE CRASH RATE
- 2X OR ABOVE STATEWIDE AVERAGE CRASH RATE
- CONGESTION HOTSPOT
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PA Turnpike to US 1

EXISTING CRASH HOTSPOTS

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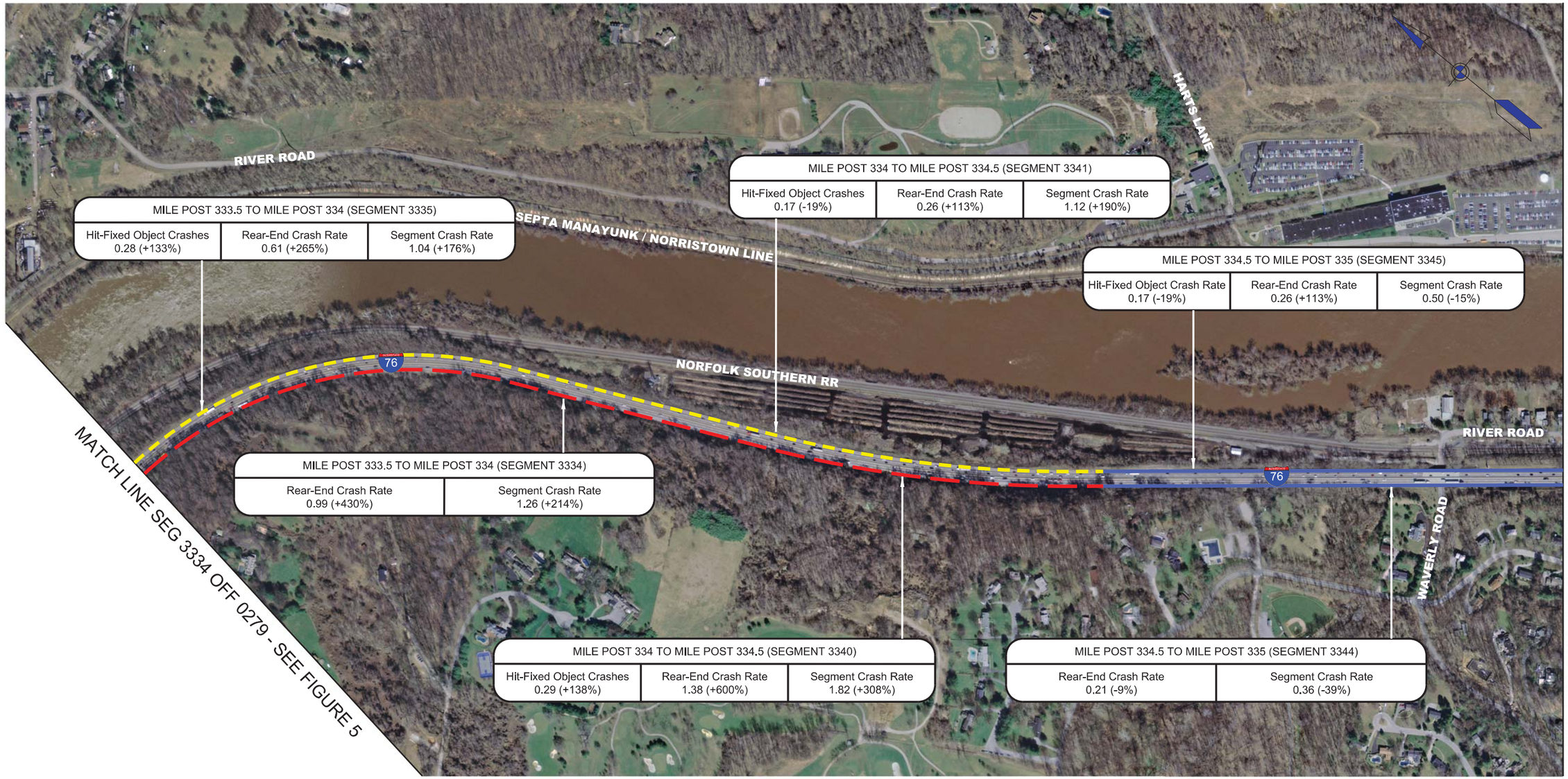
FIGURE 5



LEGEND

- BELOW STATEWIDE AVERAGE CRASH RATE
- 1X - 2X ABOVE STATEWIDE AVERAGE CRASH RATE
- 2X OR ABOVE STATEWIDE AVERAGE CRASH RATE
- CONGESTION HOTSPOT
- EXISTING DMS (DYNAMIC MESSAGE SIGN)
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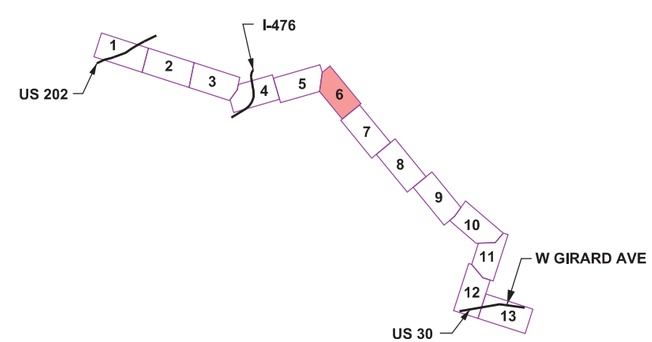

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PA Turnpike to US 1

EXISTING CRASH HOTSPOTS

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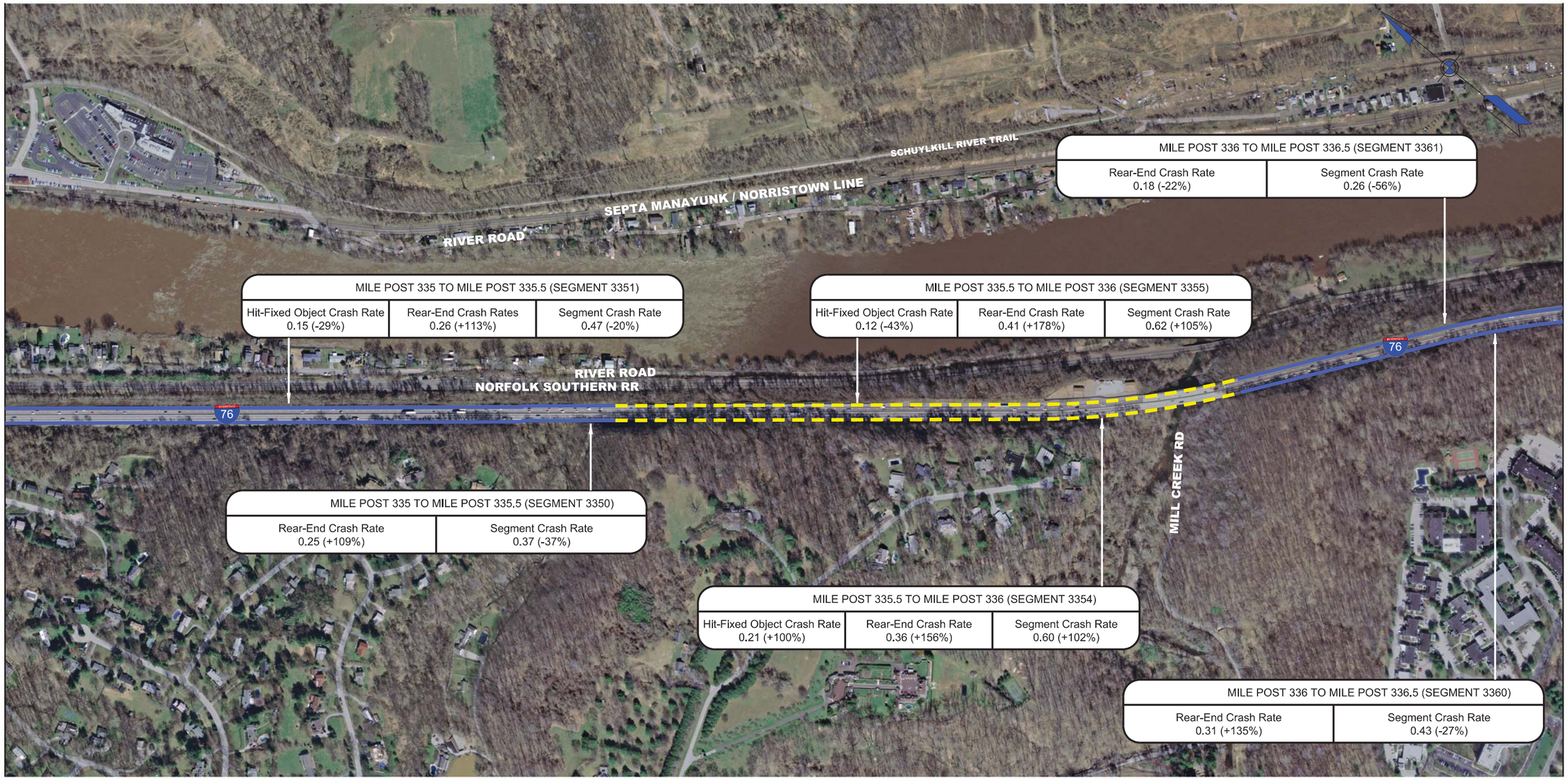
JAN 2017	FIGURE 6

MATCH LINE SEG 3344 OFF 1752 - SEE FIGURE 6



MATCH LINE SEG 3360 OFF 1605 - SEE FIGURE 8

LEGEND

- BELOW STATEWIDE AVERAGE CRASH RATE
- 1X - 2X ABOVE STATEWIDE AVERAGE CRASH RATE
- 2X OR ABOVE STATEWIDE AVERAGE CRASH RATE
- CONGESTION HOTSPOT
- EXISTING DMS (DYNAMIC MESSAGE SIGN)
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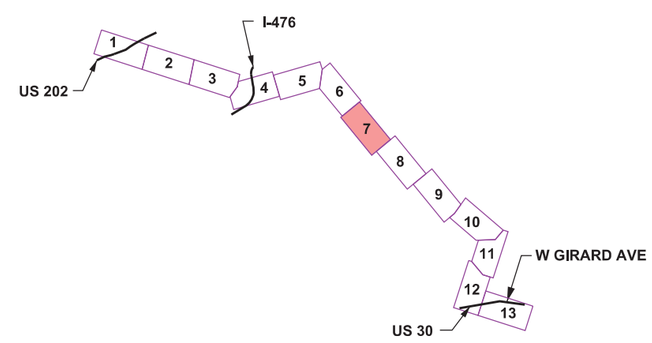

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I-76 ITS ENHANCEMENTS
PA Turnpike to US 1

EXISTING CRASH HOTSPOTS

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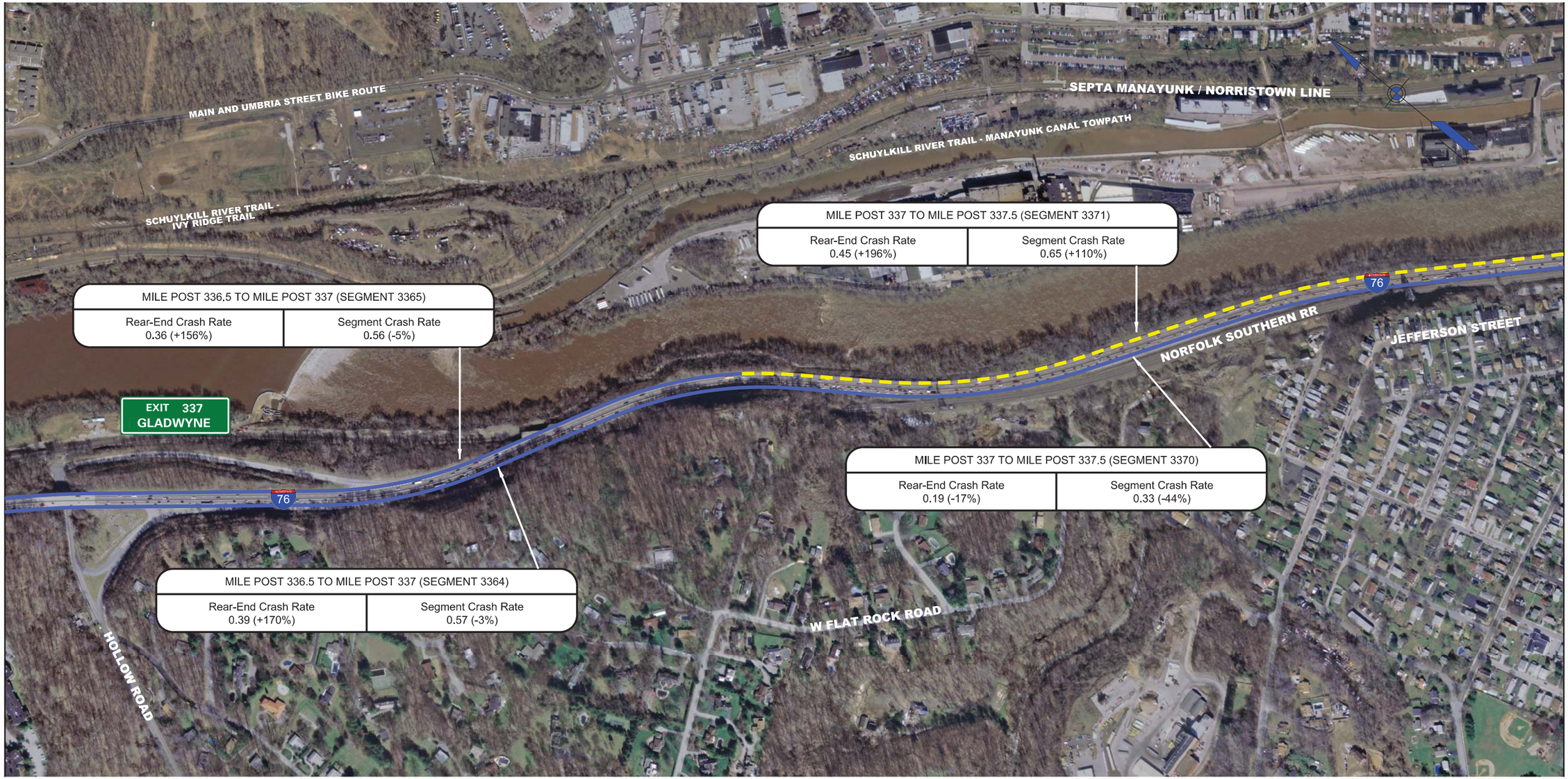
FIGURE 7

MATCH LINE SEG 3360 OFF 1605 - SEE FIGURE 7



MATCH LINE SEG 3374 OFF 0865 - SEE FIGURE 9

LEGEND

- BELOW STATEWIDE AVERAGE CRASH RATE
- 1X - 2X ABOVE STATEWIDE AVERAGE CRASH RATE
- 2X OR ABOVE STATEWIDE AVERAGE CRASH RATE
- CONGESTION HOTSPOT
- EXISTING DMS (DYNAMIC MESSAGE SIGN)
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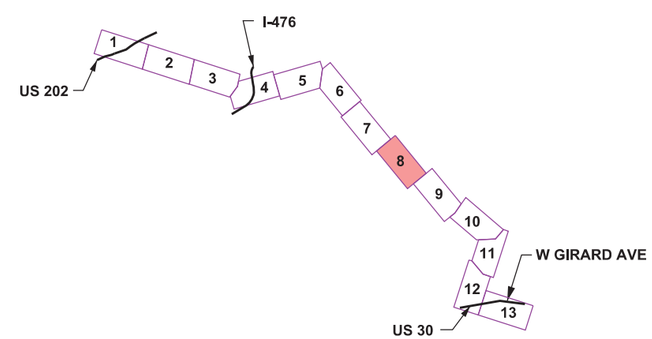

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PA Turnpike to US 1

EXISTING CRASH HOTSPOTS

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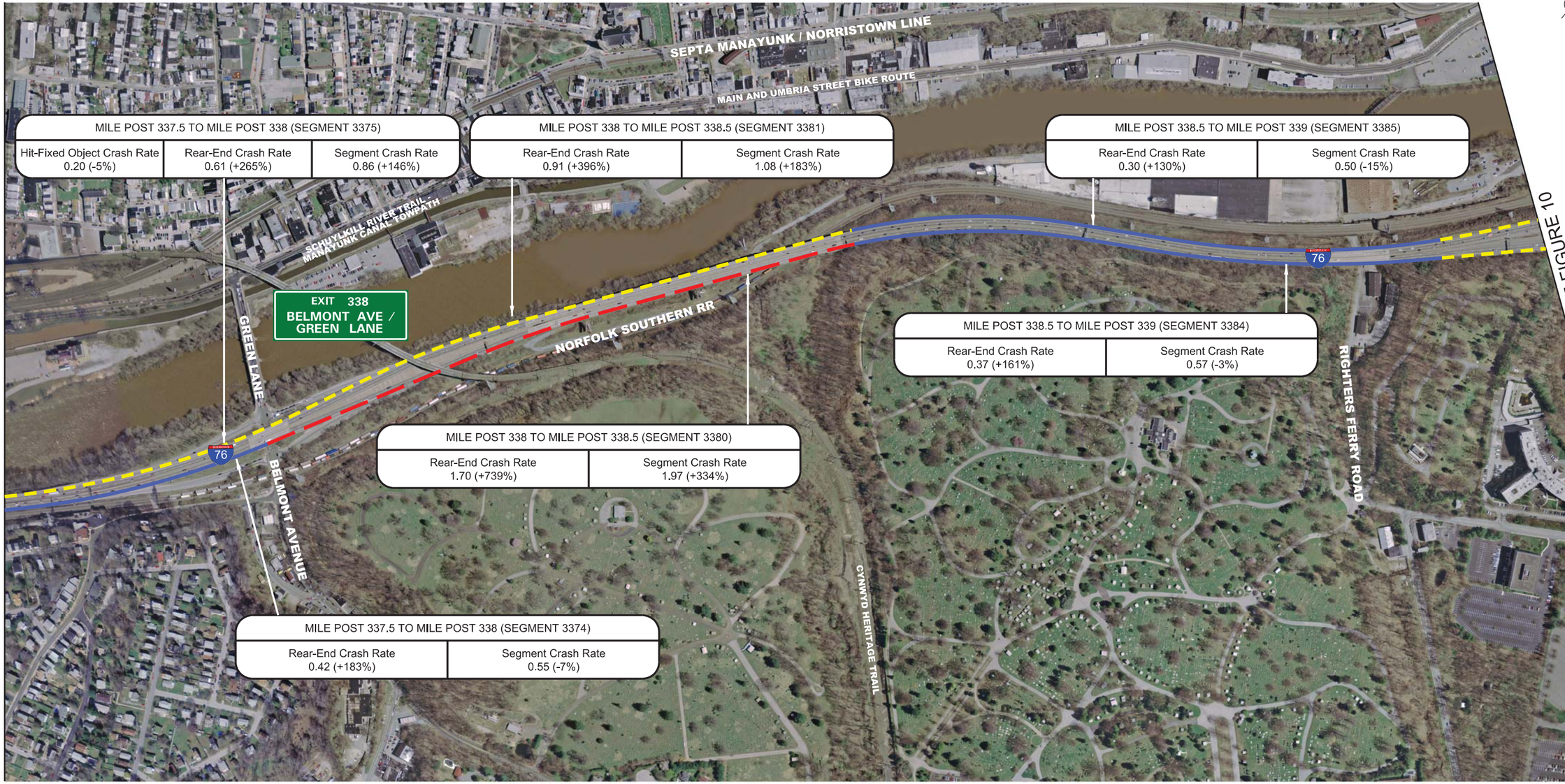
FIGURE 8

MATCH LINE SEG 3374 OFF 0865 - SEE FIGURE 8



MATCH LINE SEG 3390 OFF 0633 - SEE FIGURE 10

LEGEND

- BELOW STATEWIDE AVERAGE CRASH RATE
- 1X - 2X ABOVE STATEWIDE AVERAGE CRASH RATE
- 2X OR ABOVE STATEWIDE AVERAGE CRASH RATE
- CONGESTION HOTSPOT
- EXISTING DMS (DYNAMIC MESSAGE SIGN)
- VARIABLE SPEED LIMITS
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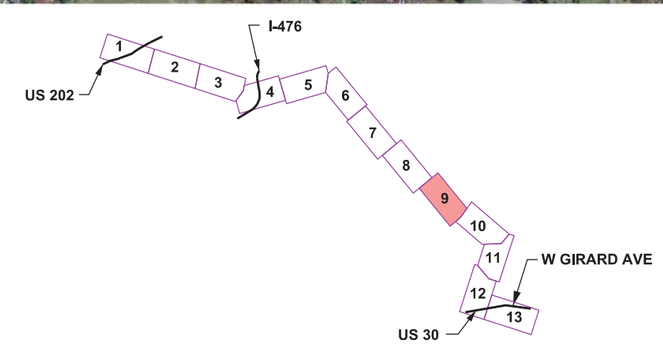

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PA Turnpike to US 1

EXISTING CRASH HOTSPOTS

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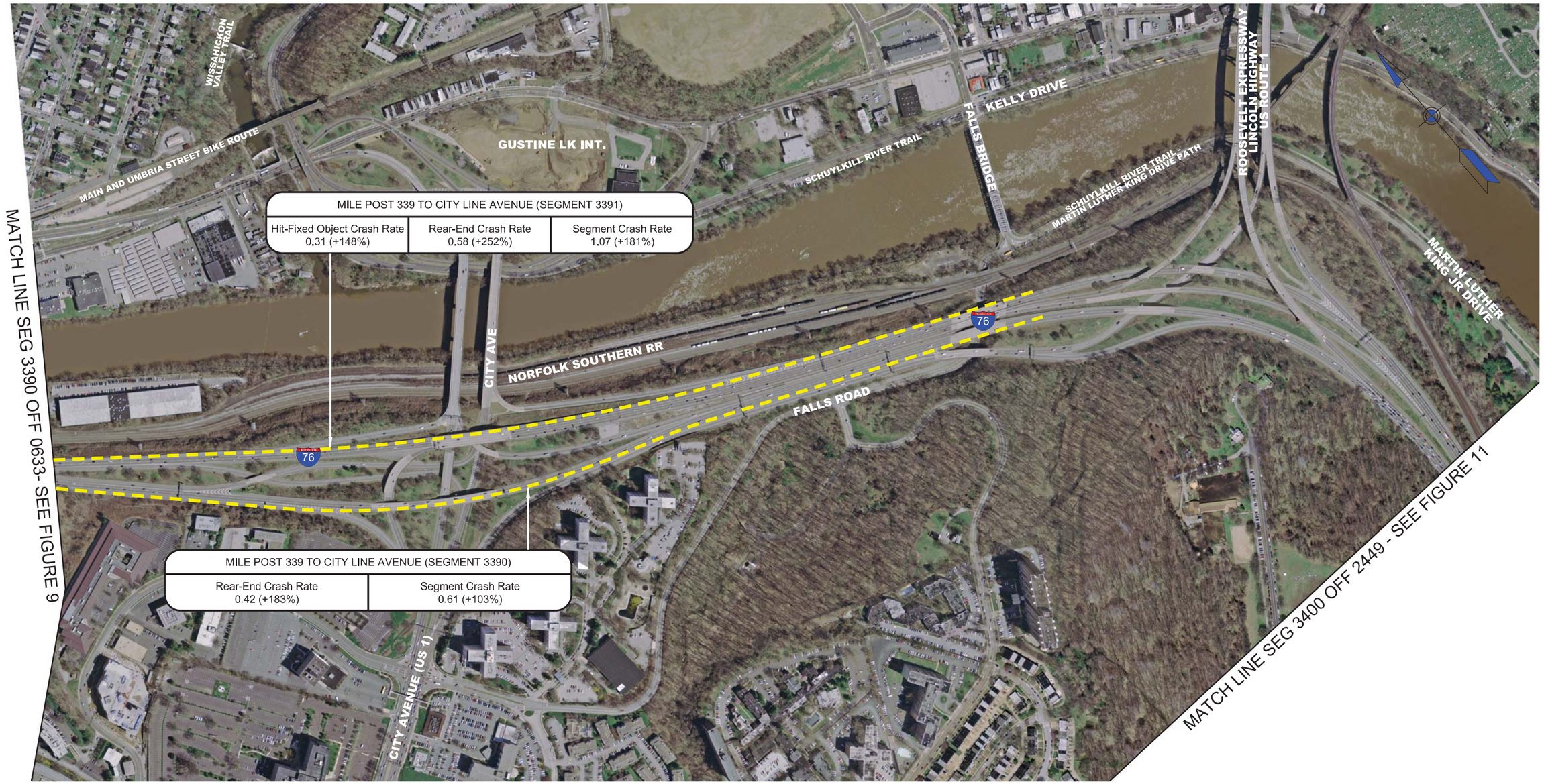
JAN 2017	FIGURE 9



LEGEND

- BELOW STATEWIDE AVERAGE CRASH RATE
- 1X - 2X ABOVE STATEWIDE AVERAGE CRASH RATE
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- CONGESTION HOTSPOT
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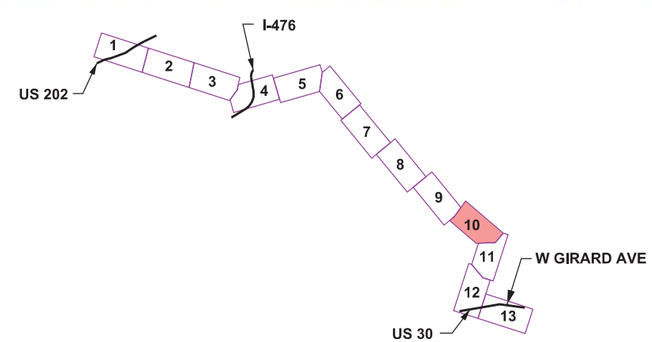

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PA Turnpike to US 1

EXISTING CRASH HOTSPOTS

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Appendix B:

Pennsylvania Code 212.08

§ 212.108. Speed limits.

(a) *General*. This section applies to maximum speed limits established according to 75 Pa.C.S. § § 3362 and 3363 (relating to maximum speed limits; and alteration of maximum limits). Engineering and traffic studies are not required for statutory speed limits, but documentation should be on file for urban districts and residence districts to show that the requirements defined in the Vehicle Code are satisfied.

(b) *Engineering and traffic studies*. Speed limits established in accordance with 75 Pa.C.S. § 3363 may be established in multiples of 5 miles per hour up to the maximum lawful speed. The speed limit should be within 5 miles per hour of the average 85th percentile speed or the safe-running speed on the section of highway, except the speed limit may be reduced up to 10 miles per hour below either of these values if one or more of the following conditions are satisfied:

(1) A major portion of the highway has insufficient stopping sight distance if traveling at the 85th percentile speed or the safe-running speed.

(2) The available corner sight distance on side roads is less than the necessary stopping sight distance values for through vehicles.

(3) The majority of crashes are related to excessive speed and the crash rate during a minimum 12-month period is greater than the applicable rate in the most recent high-crash rate or high-crash severity rate table included in the appendix of Official Traffic-Control Devices (Department Publication 212). Crashes related to excessive speed include those crashes with causation factors of driving too fast for conditions, turning without clearance or failing to yield right-of-way.

(c) *Variable speed limits*. To improve safety, speed limits may be changed as a function of traffic speeds or densities, weather or roadway conditions or other factors.

(d) *Special speed limits*.

(1) Within a rest area or welcome center, a 25 mile per hour speed limit may be established without the need for an engineering and traffic study if pedestrians walk across the access roadways between the parking lot and the rest facilities.

(2) Within a toll plaza or a truck weight station, an appropriate speed limit may be established without an engineering and traffic study by the authorities in charge to enforce the safety of the operations or to protect the scales.

(e) *Posting of speed limits*. A Speed Limit Sign (R2-1) or variable speed limit sign showing the maximum speed limit shall be placed on the right side of the highway at the beginning of each numerical change in the speed limit, but an additional sign may also be installed on the left side of the highway. If the new speed limit begins at an intersection, the first sign should be installed within 200 feet beyond the intersection. The placement of this sign must satisfy both the requirement to post the beginning of the new speed limit and the requirement to post the end of the previous speed limit. Additional requirements for posting are as follows:

(1) Speed limits of 50 miles per hour or less shall be posted as follows:

(i) A Reduced Speed (

—

) Ahead Sign (R2-5), or a Speed Reduction Sign (W3-5), shall be placed on the right side of the highway 500 to 1,000 feet before the beginning of every speed reduction unless one of the following applies:

(A) The speed reduction is 10 miles per hour or less.

(B) The speed reduction begins at an intersection and all traffic entering the roadway with the speed reduction has to either stop at a Stop Sign (R1-1) or make a turn.

(C) The new speed limit is posted on variable speed limit signs.

(ii) Speed Limit Signs (R2-1) or a variable speed limit sign showing the maximum speed shall be placed on the right side of the highway at the beginning of the speed limit and at intervals not greater than 1/2 mile throughout the area with the speed limit.

(iii) The end of a speed limit is typically identified by the placement of a sign indicating a new speed limit, but the End Plaque (R2-10) may be placed above a Speed Limit Sign (R2-1) at the end of the zone if the appropriate speed limit is not known on the following section of roadway.

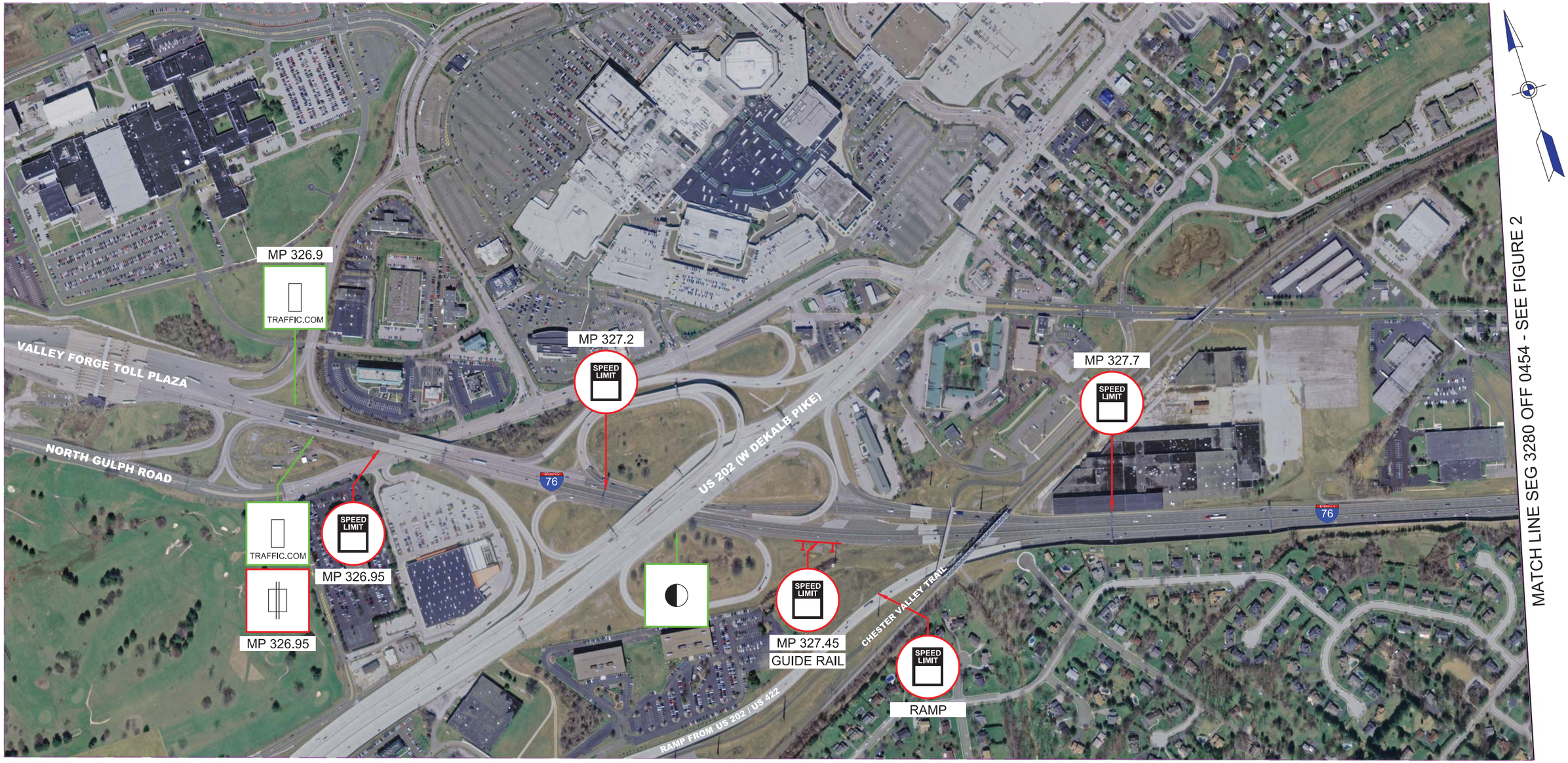
(2) On freeways, a Speed Limit Sign (R2-1) shall be installed after each interchange unless insufficient space exists for the signs.

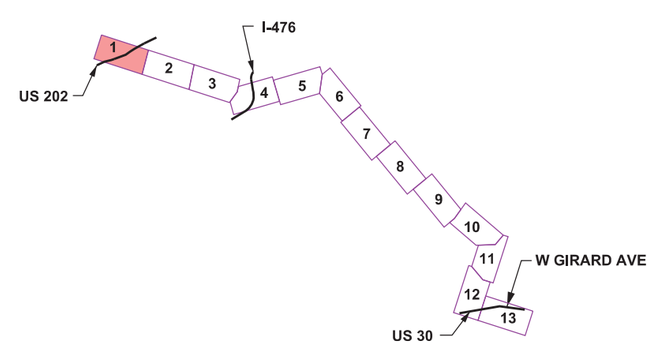
Cross References

This section cited in 67 Pa. Code § 212.109 (relating to bridge speed limit).

Appendix C:

Preliminary VSL & QW Device Locations





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LEGEND

- EXISTING CCTV CAMERA
- EXISTING DETECTOR
- EXISTING TRAFFIC.COM DETECTOR
- EXISTING DMS
- EXISTING TAG READER (E-ZPASS)
- PROPOSED VARIABLE SPEED LIMIT
- PROPOSED DMS
- PROPOSED DETECTOR
- PROPOSED GUIDE RAIL

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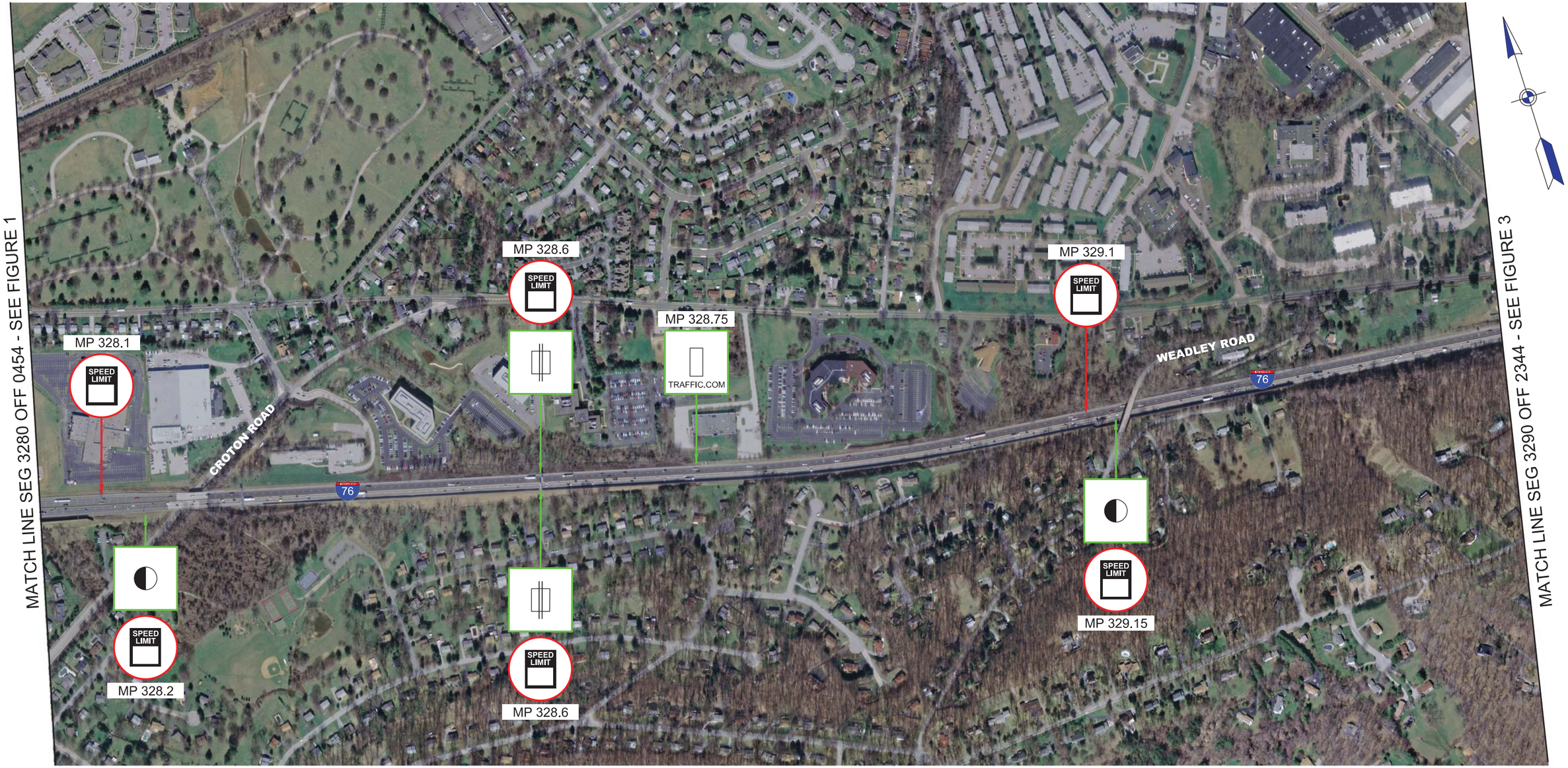
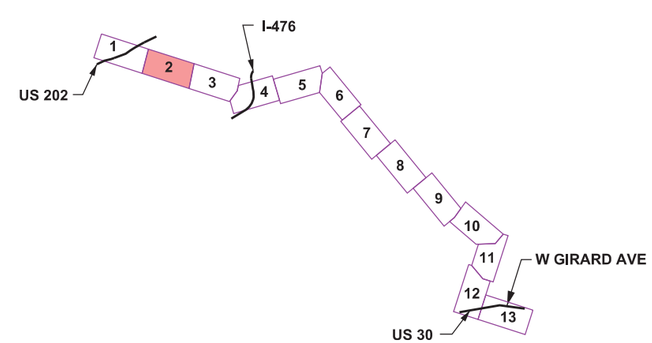
SEPT 2016	FIGURE 1





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LEGEND

- EXISTING CCTV CAMERA
- EXISTING DETECTOR
- EXISTING TRAFFIC.COM DETECTOR
- EXISTING DMS
- EXISTING TAG READER (E-ZPASS)
- PROPOSED VARIABLE SPEED LIMIT
- PROPOSED DMS
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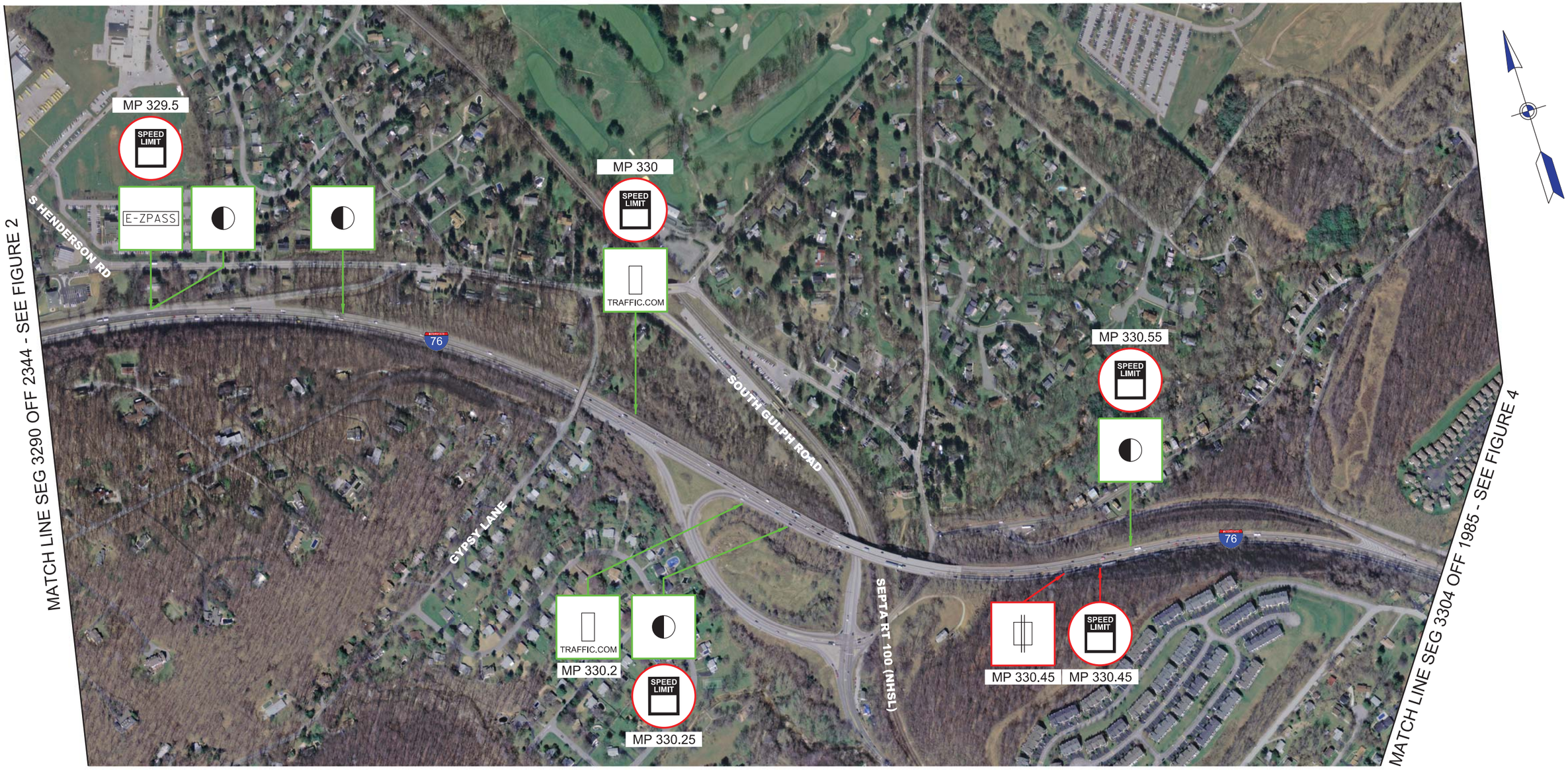
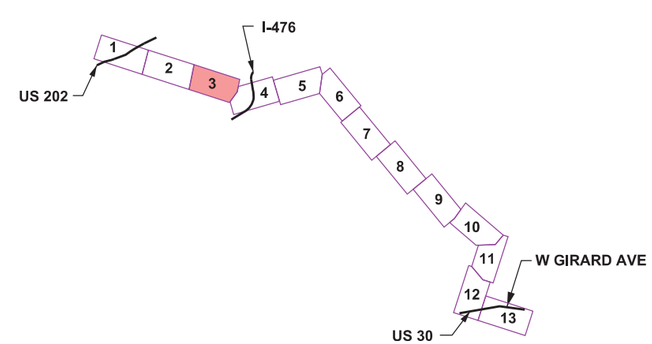
DAWOOD

SEPT 2016	FIGURE 2





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LEGEND

- EXISTING CCTV CAMERA
- EXISTING DETECTOR
- EXISTING TRAFFIC.COM DETECTOR
- EXISTING DMS
- EXISTING TAG READER
- PROPOSED VARIABLE SPEED LIMIT
- PROPOSED DMS
- PROPOSED DETECTOR
- PROPOSED GUIDE RAIL

NOTE: THE LEGAL RIGHT- OF- WAY LINES FOR LIMITED ACCESS AS SHOWN ON THE ROADWAY PLANS ARE FOR INFORMATION PURPOSES ONLY AND HAVE NOT BEEN VERIFIED.
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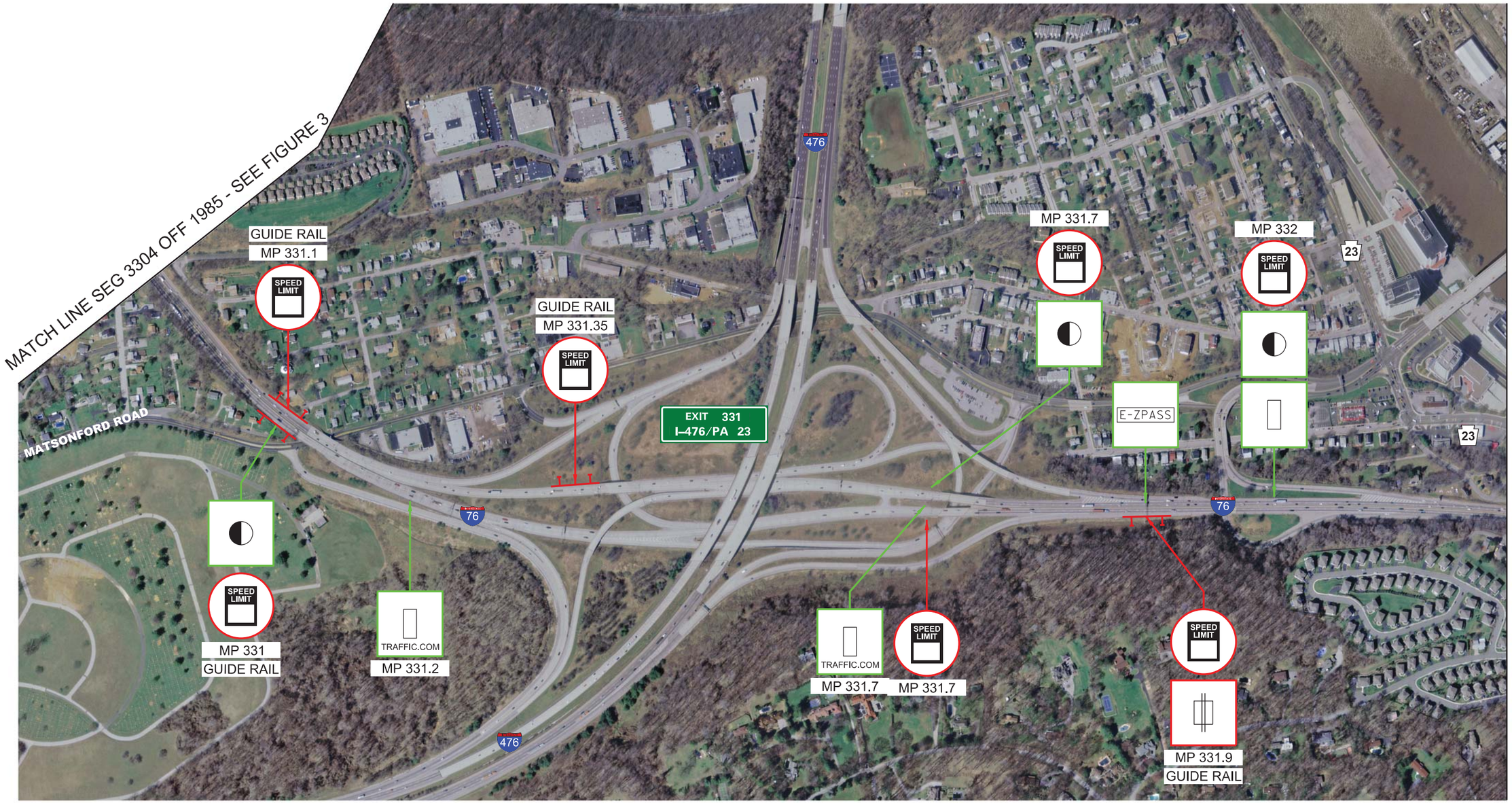
I-76 ITS ENHANCEMENTS
PA Turnpike to US 1

JACOBS
RK&K
DAWOOD

SEPT 2016	FIGURE 3



LEGEND

- EXISTING CCTV CAMERA
- EXISTING DETECTOR
- EXISTING TRAFFIC.COM DETECTOR
- EXISTING DMS
- EXISTING TAG READER
- PROPOSED VARIABLE SPEED LIMIT
- PROPOSED DMS
- PROPOSED DETECTOR
- PROPOSED GUIDE RAIL

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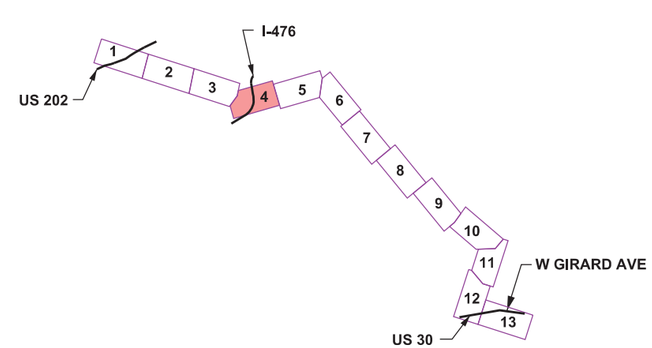

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PA Turnpike to US 1

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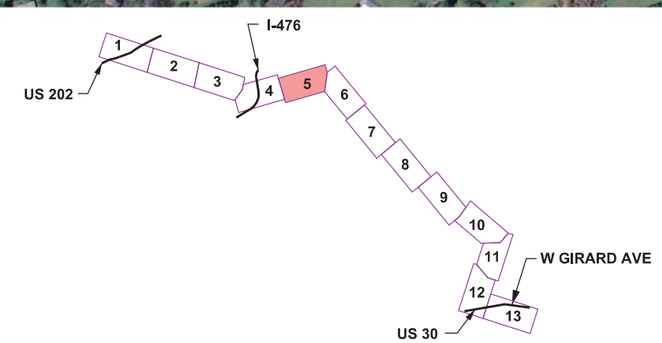
DAWOOD

SEPT 2016	FIGURE 4



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LEGEND

- EXISTING CCTV CAMERA
- EXISTING DETECTOR
- EXISTING TRAFFIC.COM DETECTOR
- EXISTING DMS
- EXISTING TAG READER (E-ZPASS)
- PROPOSED VARIABLE SPEED LIMIT
- PROPOSED DMS
- PROPOSED DETECTOR
- PROPOSED GUIDE RAIL

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PA Turnpike to US 1

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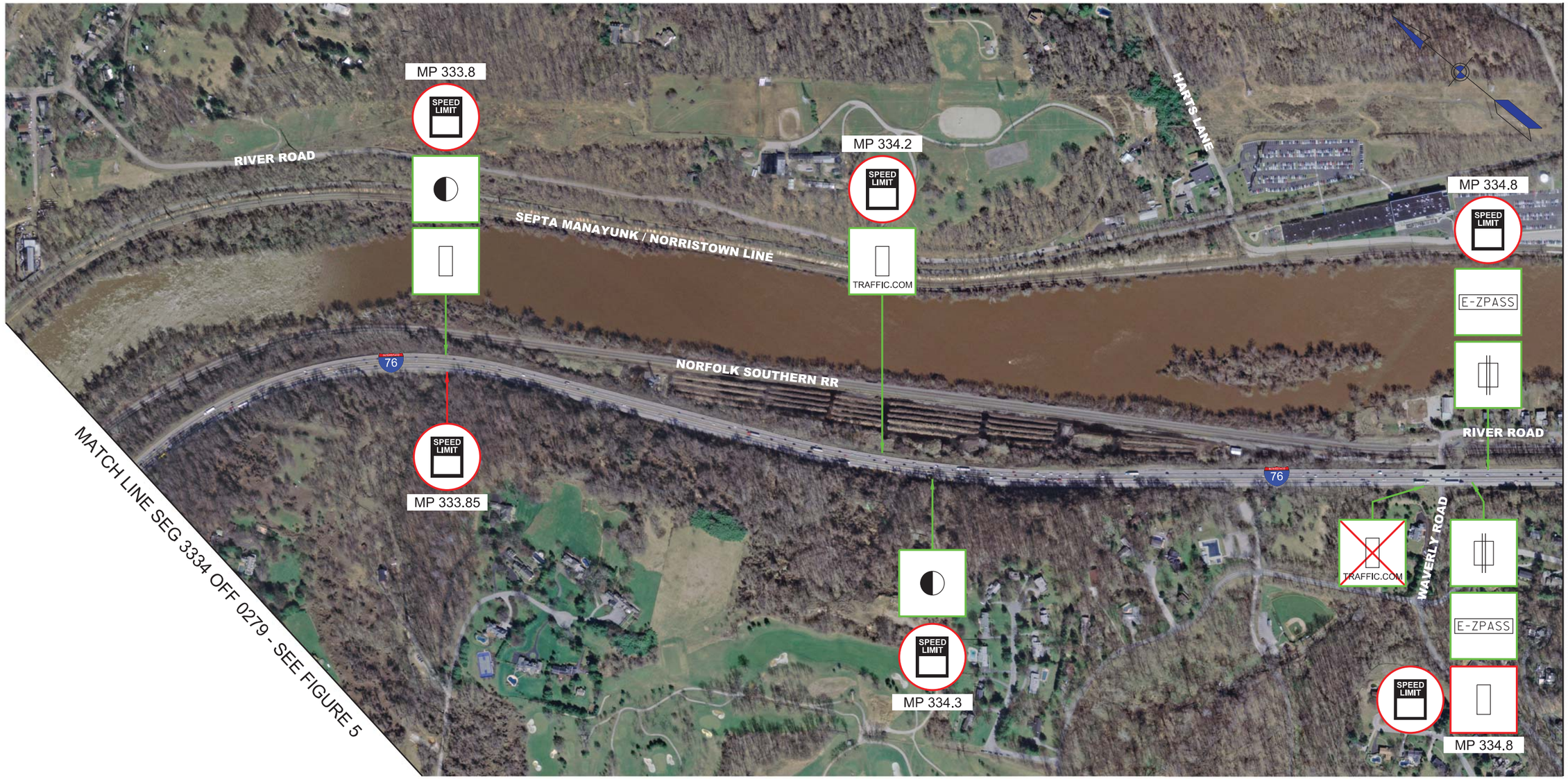
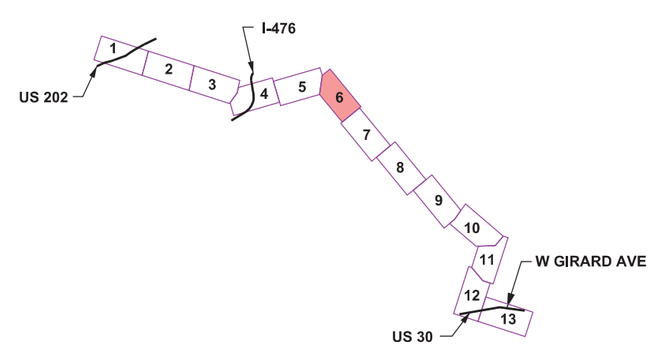
SEPT 2016	FIGURE 5





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LEGEND

- EXISTING CCTV CAMERA
- EXISTING DETECTOR
- EXISTING TRAFFIC.COM DETECTOR
- EXISTING DMS
- EXISTING TAG READER
- PROPOSED VARIABLE SPEED LIMIT
- PROPOSED DMS
- PROPOSED DETECTOR
- PROPOSED GUIDE RAIL

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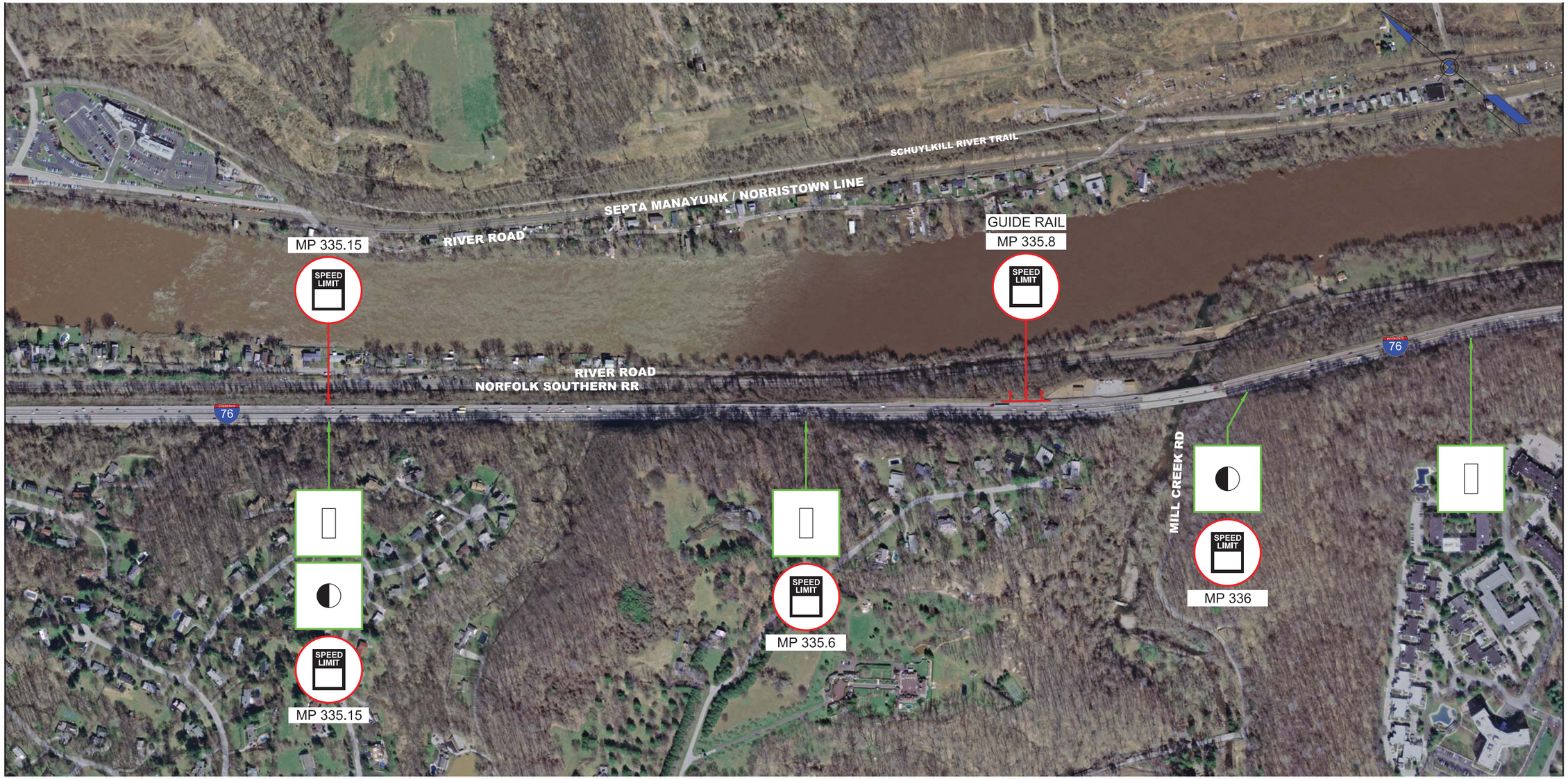
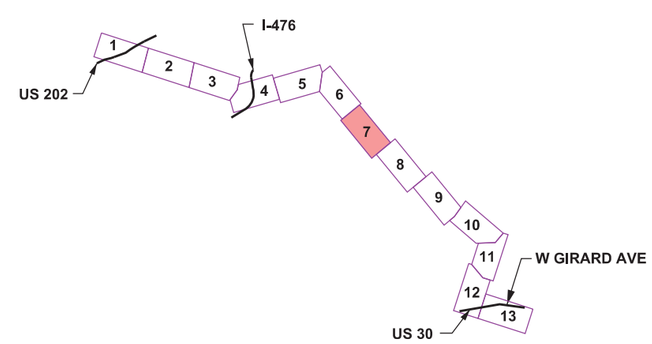
SEPT 2016	FIGURE 6

MATCH LINE SEG 3344 OFF 1752 - SEE FIGURE 6



MATCH LINE SEG 3360 OFF 1605 - SEE FIGURE 8



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LEGEND

- EXISTING CCTV CAMERA
- EXISTING DETECTOR
- EXISTING TRAFFIC.COM DETECTOR
- EXISTING DMS
- EXISTING TAG READER
- PROPOSED VARIABLE SPEED LIMIT
- PROPOSED DMS
- PROPOSED DETECTOR
- PROPOSED GUIDE RAIL

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PA Turnpike to US 1

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SEPT 2016	FIGURE 7

MATCH LINE SEG 3360 OFF 1605 - SEE FIGURE 7

MATCH LINE SEG 3374 OFF 0865 - SEE FIGURE 9

LEGEND

- EXISTING CCTV CAMERA
- EXISTING DETECTOR
- EXISTING TRAFFIC.COM DETECTOR
- EXISTING DMS
- EXISTING TAG READER (E-ZPASS)
- PROPOSED VARIABLE SPEED LIMIT
- PROPOSED DMS
- PROPOSED DETECTOR
- PROPOSED GUIDE RAIL

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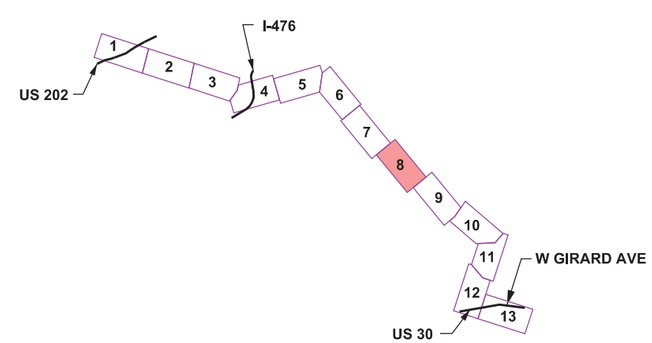

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PA Turnpike to US 1

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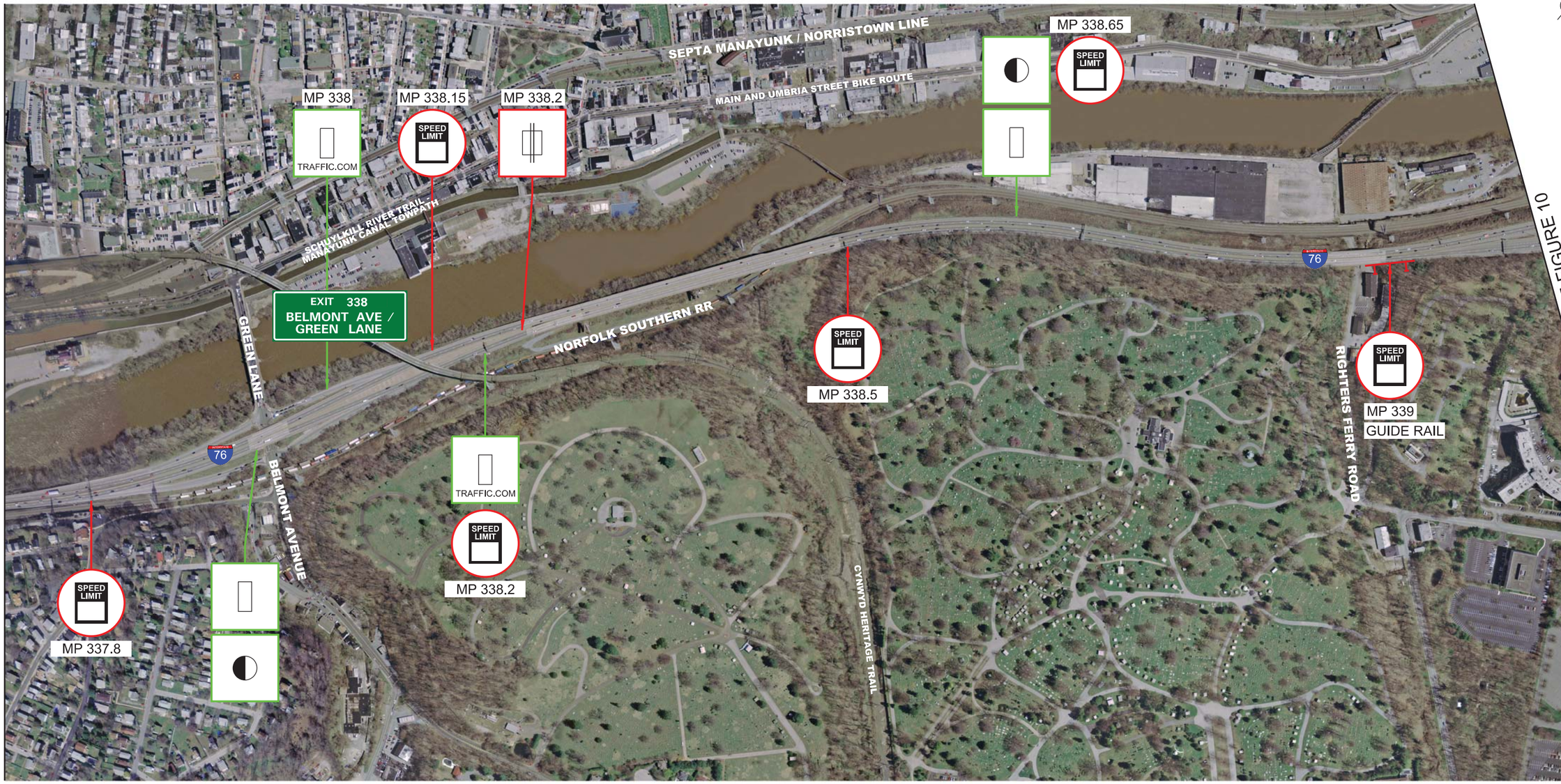
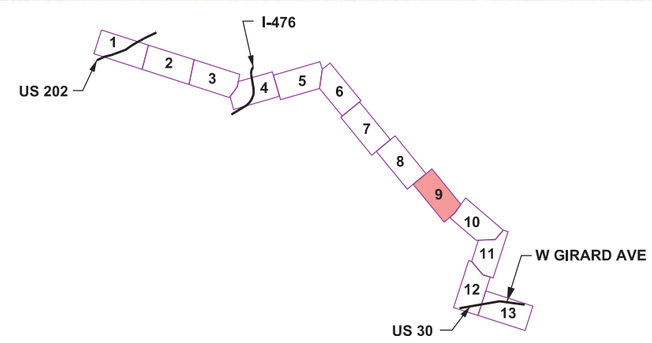
SEPT 2016	FIGURE 8

MATCH LINE SEG 3374 OFF 0865 - SEE FIGURE 8



MATCH LINE SEG 3390 OFF 0633 - SEE FIGURE 10



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LEGEND

- EXISTING CCTV CAMERA
- EXISTING DETECTOR
- EXISTING TRAFFIC.COM DETECTOR
- EXISTING DMS
- EXISTING TAG READER
- PROPOSED VARIABLE SPEED LIMIT
- PROPOSED DMS
- PROPOSED DETECTOR
- PROPOSED GUIDE RAIL

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PA Turnpike to US 1

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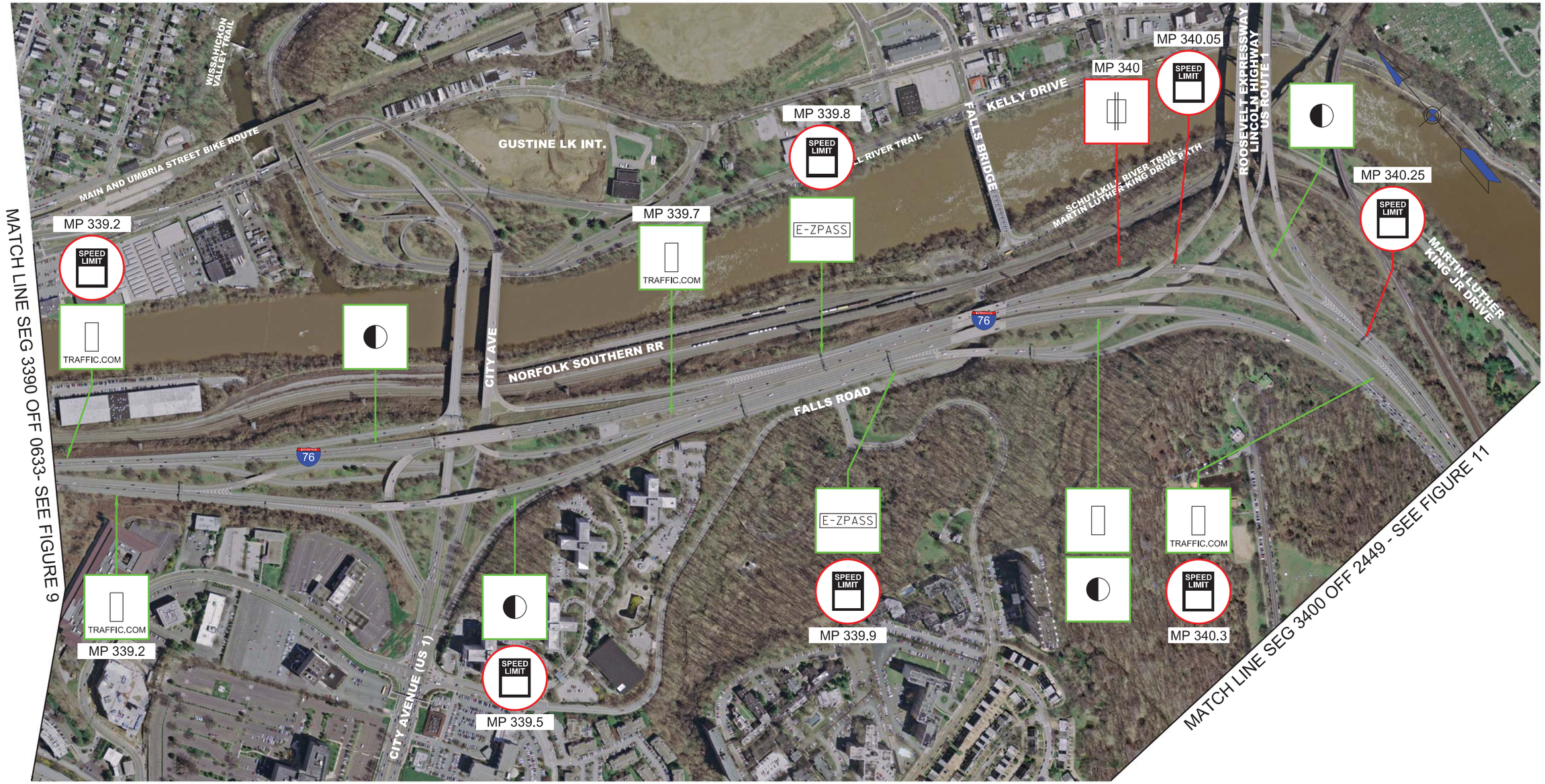
SEPT 2016	FIGURE 9



LEGEND

- EXISTING CCTV CAMERA
- EXISTING DETECTOR
- EXISTING TRAFFIC.COM DETECTOR
- EXISTING DMS
- EXISTING TAG READER
- PROPOSED VARIABLE SPEED LIMIT
- PROPOSED DMS
- PROPOSED DETECTOR
- PROPOSED GUIDE RAIL

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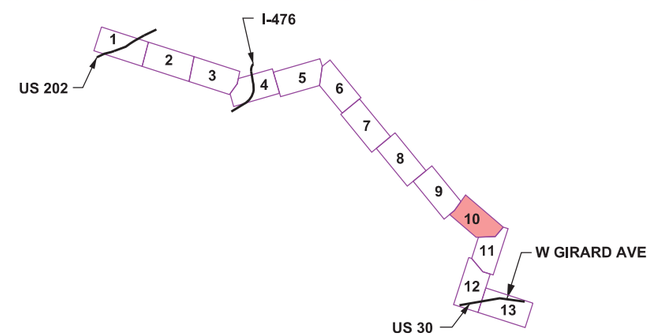

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PA Turnpike to US 1

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SEPT 2016	FIGURE 10

APPENDIX B: TRAVEL TIME MEMO EXAMPLE

This white paper recommends primary and, if appropriate, secondary message formats for each of the DMS scheduled to display travel times throughout the limits of the SR 0422 Corridor project, as well as for signs outside of the project limits that can be utilized as origins for destinations within the Corridor. All formats have been developed with the intent of providing clear, simple, and consistent messages that are beneficial to all motorists – both daily commuters as well as motorists who are unfamiliar with the area.

In general, recommended messages for center-mount DMS are limited to one phase and 18 characters per line. Destination references are generally those utilized on existing static directional signing, while taking character limits into consideration. Interstate, US Route, and PA Route designations are utilized as often as possible to limit the number of characters. All messages on center-mount DMS provide both mileage, which is most useful to unfamiliar drivers, and travel time, which is most useful to daily commuters.

Recommended messages for Type A post mounted DMS are limited by a smaller sign panel size. Depending on the manufacturer, if the sign provides 13 characters per line and 3 lines of text, then only travel time to a destination can be displayed. If the sign provides 15 characters per line and 3 lines of text, then both travel time and distance to a destination can be displayed. The latter is the case for most Type A post mounted DMS on this project and is also consistent with recent Type A post mounted DMS installations in District 6-0.

PennDOT originally developed a standard travel time message format for the RTMS-based travel time system deployed along SR 0202, SR 0030, and SR 0100 under the SR 0202, Section 3IT project. The message format connected each origin DMS to a single downstream destination, and is as follows:

AVG TRAVEL TIME
TO DESTINATION
XXMI XXMIN

The travel time system deployed along SR 0202 under the SR 0202, Section 320 project differs from the Section 3IT system in that it covers more miles of roadway and enables PennDOT to display travel times to multiple destinations on a single DMS. In these cases, the dual destination message is the primary format; however, a single destination option is also provided if PennDOT determines that a dual destination message appears too cluttered. The general message format for dual destinations is as follows:

AVG TRAVEL TIME TO
DEST1 (XXMI) XXMIN
DEST2 (XXMI) XXMIN

PennDOT has expanded its detection capabilities through various ITS projects and is able to post travel time messages along intersecting routes in advance of major system interchanges. These messages provide the travel time from the DMS location to a destination along an intersecting route. The general format for these messages is as follows:

TIME TO DESTINATION
VIA ROUTE & DIRECTION
XXMI XXMIN

TRAVEL TIME LINKS

The Department has determined that the level of confidence for INRIX data is acceptable for travel time use along SR 0422. At the time that this white paper is being written, INRIX data is being utilized for travel time messages for existing DMS installed under SRB and therefore it is assumed the data is acceptable for travel times along both the primary alternate route (Ben Franklin Highway / High Street / Ridge Pike) and secondary alternate route (SR 0724 / SR 0023).

Table 1 lists the SR 0422 Corridor travel time links utilizing INRIX data. The appropriate sublinks will be configured by the ATMS vendor.

Figure 1 presents the travel time links by grouping all associated DMS with each destination. Links are denoted as either the proposed primary message, proposed secondary message, or existing message for each DMS. One DMS may be associated with more than one destination.

Figure 2 presents the travel time links on the overall map view of the Corridor.

Link	Origin	Destination	Route	Direction	Data Source
1	D422W_05	PA 662	SR 422	WB	INRIX
2	D422W_06	PA 662	SR 422	WB	INRIX
3	D422W_07	PA 662	SR 422	WB	INRIX
4	D422W_12	PA 662	SR 422	WB	INRIX
5	D422E_21	PA 100	SR 422	EB	INRIX
6	D422E_20	PA 100	SR 422	EB	INRIX
7	D422E_18	PA 100	SR 422	EB	INRIX
8	*D422W_04*	PA 100	SR 422	WB	INRIX
9	D422W_05	PA 100	SR 422	WB	INRIX
10	D422W_06	PA 100	SR 422	WB	INRIX
11	D422W_07	PA 100	SR 422	WB	INRIX
12	*D3031N_01*	PA 100	Gulph Rd / SR 422	WB	INRIX
13	*D422W_04*	SANATOGA	SR 422	WB	INRIX
14	D422W_05	SANATOGA	SR 422	WB	INRIX
15	D422E_20	PA 29	SR 422	EB	INRIX
16	D422E_18	PA 29	SR 422	EB	INRIX
17	D422E_11	PA 29	SR 422	EB	INRIX
18	D422E_10	PA 29	SR 422	EB	INRIX
19	D422E_09	PA 29	SR 422	EB	INRIX
20	D422W_05	PA 29	SR 422	WB	INRIX
21	D023W_04	PA 29	SR 23 / SR 422	WB	INRIX
22	D3031N_01	PA 29	Gulph Rd / SR 422	WB	INRIX
23	D202N_15	PA 29	SR 202 / SR 4031	WB	INRIX
24	*D422E_08*	SR 363	SR 422	EB	INRIX
25	*D422E_02*	SR 363	SR 422	EB	INRIX
26	D422E_21	PA 23	SR 422	EB	INRIX
27	D422E_20	PA 23	SR 422	EB	INRIX
28	*D422E_08*	PA 23	SR 422	EB	INRIX

29	D724E_01	PA 23	SR 724	EB	INRIX
30	D422E_21	US 202 / I-76	SR 422	EB	INRIX
31	D422E_20	US 202 / I-76	SR 422	EB	INRIX
32	D422E_18	US 202 / I-76	SR 422	EB	INRIX
33	D422E_11	US 202 / I-76	SR 422	EB	INRIX
34	D422E_10	US 202 / I-76	SR 422	EB	INRIX
35	D422E_09	US 202 / I-76	SR 422	EB	INRIX
36	*D422E_08*	US 202 / I-76	SR 422	EB	INRIX
37	*D422E_02*	US 202 / I-76	SR 422	EB	INRIX
38	*D422E_01*	US 202 / I-76	SR 422	EB	INRIX
39	D724E_01	US 202 / I-76	SR 422	EB	INRIX
40	*D113N_01*	US 202 / I-76	SR 113 / SR 29	NB	INRIX
41	D100N_20	US 202 / I-76	SR 100	NB	INRIX
42	D100S_21	US 202 / I-76	SR 100	SB	INRIX
43	*D422E_03*	I-476	SR 422	EB	INRIX
44	*D422E_03*	US 30	SR 422	EB	INRIX
45	D724E_02	US 422	SR 724/SR 23	EB	INRIX
46	*D023E_05*	US 422	SR 23	EB	INRIX
47	*D113N_01*	US 422	SR 113	NB	INRIX

Table 1 SR 0422 Corridor Travel Time Links

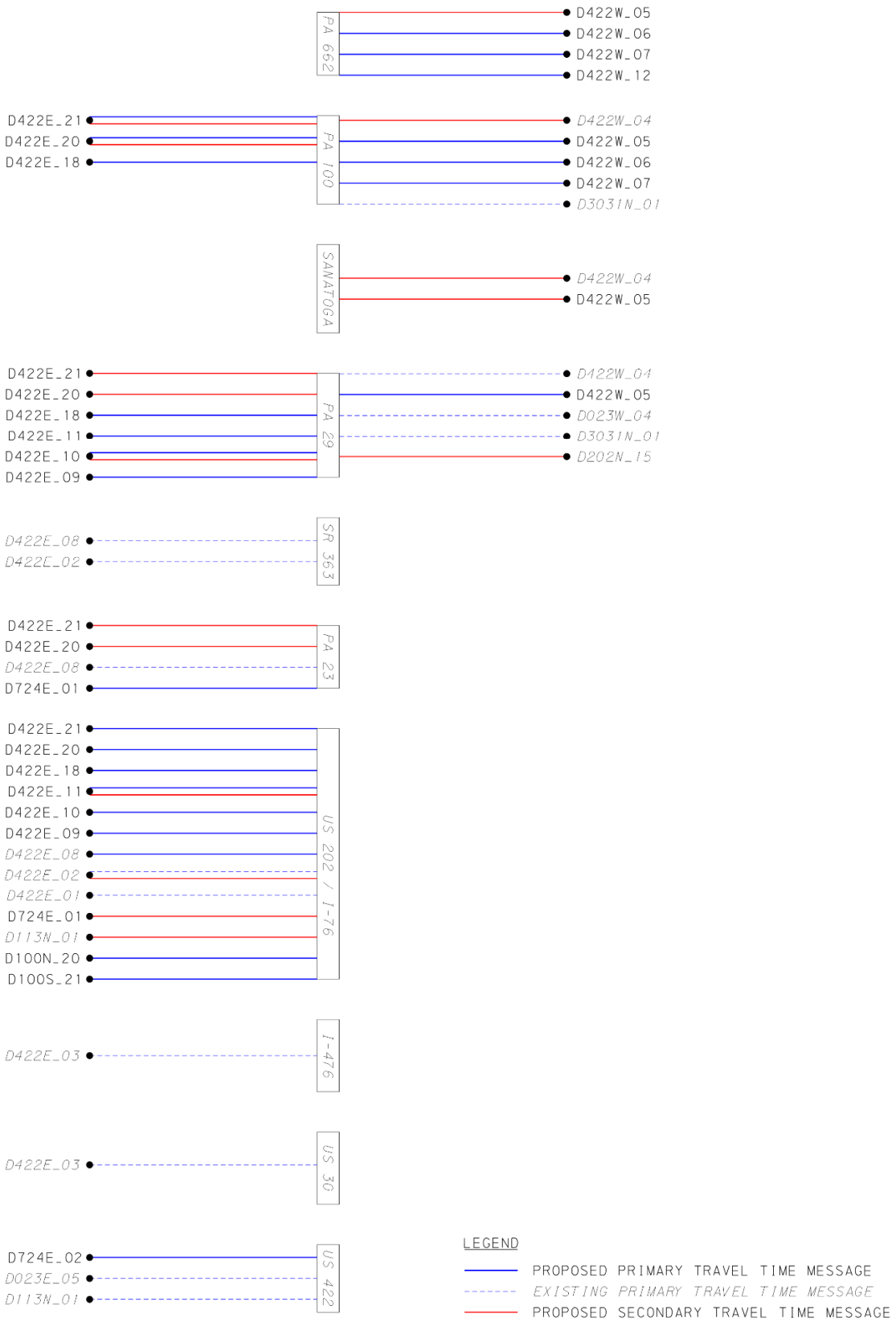


Figure 1 DMS with Corresponding Travel Time Destinations (Utilizing INRIX Data)

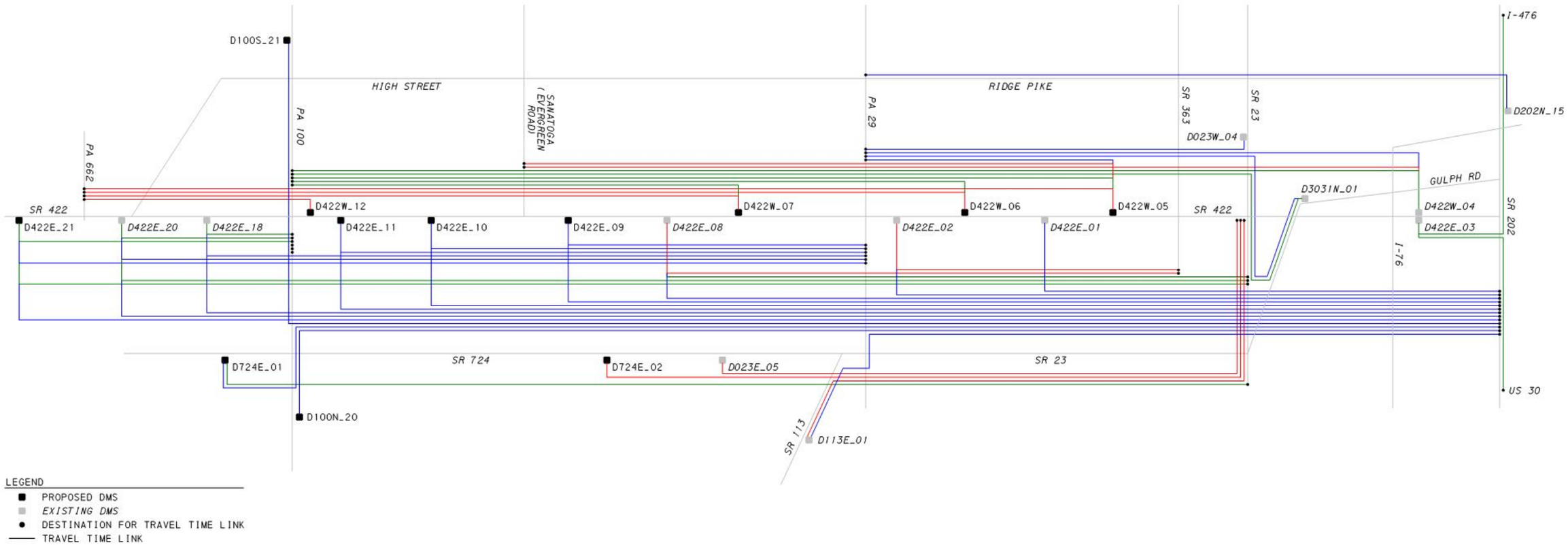


Figure 2 SR 0422 Corridor Travel Time Links Overview

TRAVEL TIME MESSAGES

SR 0422 EB DMS

D422E_21 (proposed under SR 0422, Section M1B) will be a Type A DMS located at Old Airport Road in Douglassville and is proposed to provide 3 lines of 15 characters in 12" text.

Travel Time Message	
TRAVEL TIME TO PA 100 XXMIN US 202 XXMIN	Proposed Primary
TRAVEL TIME TO PA 29 XXMIN PA 23 XXMIN	Proposed Alternate
TRAVEL TIME TO PA 100 XXMIN VIA HIGH ST	Proposed Alternate

D422E_20 (recently installed under SR 0422, Section M2C) is a Type A DMS located east of River Bridge Road in Douglassville and provides 3 lines of 15 characters in 12" text.

Travel Time Message	
TRAVEL TIME TO PA 100 XXMIN US 202 XXMIN	Proposed Primary
TRAVEL TIME TO PA 29 XXMIN PA 23 XXMIN	Proposed Alternate
TRAVEL TIME TO PA 100 XXMIN VIA HIGH ST	Proposed Alternate

D422E_18 (recently installed under SR 0422, Section M2C) is a center-mount DMS located at the Stowe exit and provides 3 lines of 18 characters in 18" text.

Travel Time Message	
AVG TRAVEL TIME TO PA 29 XMI XXMIN 202/I-76 XMI XXMIN	Proposed Primary

D422E_11 (proposed under SR 0422, Section M1B) will be a center-mount DMS located between the Hanover Street and Keim Street exits and is proposed to provide 3 lines of 18 characters in 18" text.

Travel Time Message	
AVG TRAVEL TIME TO PA 29 XMI XXMIN 202/I-76 XMI XXMIN	Proposed Primary
TIME TO 202/I-76 VIA PA 724 / PA 23 (XMI) XXMIN	Proposed Alternate

D422E_10 (proposed under SR 0422, Section M1B) will be a center-mount DMS located near Pleasantview Road between the Armand Hammer Boulevard and Sanatoga exits and is proposed to provide 3 lines of 18 characters in 18" text.

Travel Time Message	
AVG TRAVEL TIME TO PA 29 XMI XXMIN 202/I-76 XMI XXMIN	Proposed Primary
TIME TO PA 29 VIA RIDGE PIKE XMI XXMIN	Proposed Alternate

D422E_09 (proposed under SR 0422, Section M1B) will be a center-mount DMS located near Possum Hollow Road between the Sanatoga and Limerick/Linfield exits and is proposed to provide 3 lines of 18 characters in 18" text.

Travel Time Message	
AVG TRAVEL TIME TO PA 29 XMI XXMIN 202/I-76 XMI XXMIN	Proposed Primary

D422E_08 is an existing Type A DMS located near Mingo Road between the Royersford and SR 0029 exits. It is proposed to modify the existing travel time message.

Travel Time Message	
TIME TO PA 363 XXMIN	*Existing Primary*
TRAVEL TIME TO PA 363 XXMIN I-76 XXMIN	Proposed Modified Primary

D422E_02 is an existing centermount DMS located east of Troutman Road. The existing message will remain as primary. It is proposed to add an alternate message.

Travel Time Message	
TIME TO PA 363 XMI XXMIN US 202 XMI XXMIN	*Existing Primary*
TIME TO US 202 VIA EGYPT RD / MAIN ST XXMIN	Proposed Alternate

D422E_01 is an existing centermount DMS located west of Pawlings Road. No modification to the existing travel time message is proposed.

Travel Time Message	
TIME TO US 202 XMI XXMIN	*Existing Primary*

D422E_03 is an existing centermount DMS located west of the US 202 Interchange. No modification to the existing travel time message is proposed.

Travel Time Message	
TIME TO I-476 VIA 76 EB XXMIN US 30 VIA 202 SB XXMIN	*Existing Primary*

SR 0422 WB DMS

D422W_04 is an existing overhead DMS located west of Swedesford Road. The existing message will remain as primary. It is proposed to add an alternate message.

Travel Time Message	
TIME TO PA 29 VIA US 422 XXMIN PA 23 XXMIN	*Existing Primary*
AVG TRAVEL TIME TO SANATOGA XMI XXMIN PA 100 XMI XXMIN	Proposed Alternate

D422W_05 (proposed under SR 0422, Section M1B) will be a center-mount DMS located east of Pawlings Road and is proposed to provide 3 lines of 18 characters in 18” text.

Travel Time Message	
AVG TRAVEL TIME TO PA 29 (XMI) XXMIN PA 100 (XMI) XXMIN	Proposed Primary
AVG TRAVEL TIME TO SANATOGA XMI XXMIN PA 662 XMI XXMIN	Proposed Alternate

D422W_06 (proposed under SR 0422, Section M1B) will be a center-mount DMS located west of Upper Indian Head Road and is proposed to provide 3 lines of 18 characters in 18” text. Due to its proximity to PA 29, destinations toward the western limits of the 422 Corridor are proposed.

Travel Time Message	
AVG TRAVEL TIME TO PA 100 (XMI) XXMIN PA 662 (XMI) XXMIN	Proposed Primary

D422W_07 (proposed under SR 0422, Section M1B) will be a center-mount DMS located between the SR 0029 and Royersford exits and is proposed to provide 3 lines of 18 characters in 18” text.

Travel Time Message	
AVG TRAVEL TIME TO PA 100 (XMI) XXMIN PA 662 (XMI) XXMIN	Proposed Primary

D422W_12 (proposed under SR 0422, Section M1B) will be a center-mount DMS located between the SR 0724 and Hanover Street exits and is proposed to provide 3 lines of 18 characters in 18" text. Due to its proximity to SR 0100, it is not proposed to display the associated travel time.

Travel Time Message	
AVG TRAVEL TIME TO PA 662 (XMI) XXMIN	Proposed Primary

BENJAMIN FRANKLIN HIGHWAY / HIGH ST / RIDGE PIKE DMS (PRIMARY ALTERNATE ROUTE)

DMS not are feasible along this route due insufficient right-of-way. See field view memo dated December 17, 2018 for further discussion.

SR 0724 / SR 0023 DMS (SECONDARY ALTERNATE ROUTE)

D724E_01 (proposed under SR 0422, Section M1B) will be a Type A DMS located west of the SR 0100 overpass and is proposed to provide 3 lines of 15 characters in 12" text.

Travel Time Message	
TIME TO PA 23 VIA PA 724 (XMI) XXMIN	Proposed Primary
TIME TO I-76 VIA US 422 (XMI) XXMIN	Proposed Alternate

D724E_02 (proposed under SR 0422, Section M1B) will be a Type A DMS located just east of the entrance to Spring Willow Golf Club and is proposed to provide 3 lines of 15 characters in 12" text.

Travel Time Message	
TIME TO US 422 VIA PA 23 (XMI) XXMIN	Proposed Primary

D023E_05 is an existing Type A DMS located near the intersection with Township Line Road. It is proposed to modify the existing primary travel time message.

Travel Time Message	
TIME TO US 422 XXMIN	*Existing Primary*
TIME TO US422 VIA PA 23 (XMI) XXMIN	Proposed Modified Primary

D023W_04 is an existing Type A DMS located near Moore Road in advance of the SR 0422 Interchange. No modification to the existing travel time message is proposed.

Travel Time Message	
TIME TO PA 29 VIA US 422 WB XXMIN	*Existing Primary*

SR 0113 NB DMS

D113N_01 is an existing Type A DMS located between Township Line Road and SR 0023. The existing message will remain as primary. It is proposed to add an alternate message.

Travel Time Message	
TIME TO US 422 VIA PA 23 XXMIN	*Existing Primary*
TIME TO US202 VIA 29 / 422 (XMI) XXMIN	Proposed Alternate

SR 3031 NB DMS

D3031N_01 is an existing Type A DMS located on North Gulph Road in advance of the SR 0422 overpass. No modification to the existing travel time message is proposed.

Travel Time Message	
TIME VIA US 422W TO PA 29 XXMIN TO PA 100 XX MIN	*Existing Primary*

SR 0100 SB DMS

D100S_21 (proposed under SR 0422, Section M1B) will be a Type A DMS located near the intersection with Shoemaker Road and is proposed to provide 3 lines of 15 characters in 12” text.

Travel Time Message	
TIME TO I-76 VIA US 422 (XMI) XXMIN	Proposed Primary

SR 0100 NB DMS

D100N_20 (proposed under SR 0422, Section M1B) will be a Type A DMS located near the split with South Hanover Street and is proposed to provide 3 lines of 15 characters in 12” text.

Travel Time Message	
TIME TO I-76 VIA US 422 (XMI) XXMIN	Proposed Primary

SR 0202 NB DMS

D202N_15 is an existing centermount DMS located north of Henderson Road. The existing message will remain as primary. It is proposed to add an alternate message.

Travel Time Message	
AVG TRAVEL TIME TO PA 63 (XXMI) XXMIN	*Existing Primary**
TIME TO PA 29 VIA RIDGE PIKE (XMI) XXMIN	Proposed Alternate

*Message based on SR 0202, Section 500 Travel Time White Paper

APPENDIX C: TASK H SPREADSHEET TEMPLATE

The spreadsheet provided in this appendix serves as an example of the information that the ATMS vendor would need to integrate various types of systems into the ATMS platform. This is simply an example spreadsheet, and the specific project integration information should be in accordance with PennDOT Publication 408 Section 1202 and the project special provisions.

Project Name	Project POC - PennDOT	Contractor	District	Device Type	Device Count	Device Vendor	Model	Device Protocol	Device ID	Statewide ID	District ID	IP Address

IP Address Port	Subnet Mask	Gateway	Descriptive Location	Road	Direction	Mile Marker	Latitude	Longitude	County	Community String (if applicable)	Manufacture

Model	Protocol	Dimensions (if applicable)	Detector information (if applicable)	Joystick information (if applicable)	Notes

APPENDIX D: 4/30/21 PRESENTATION SLIDES

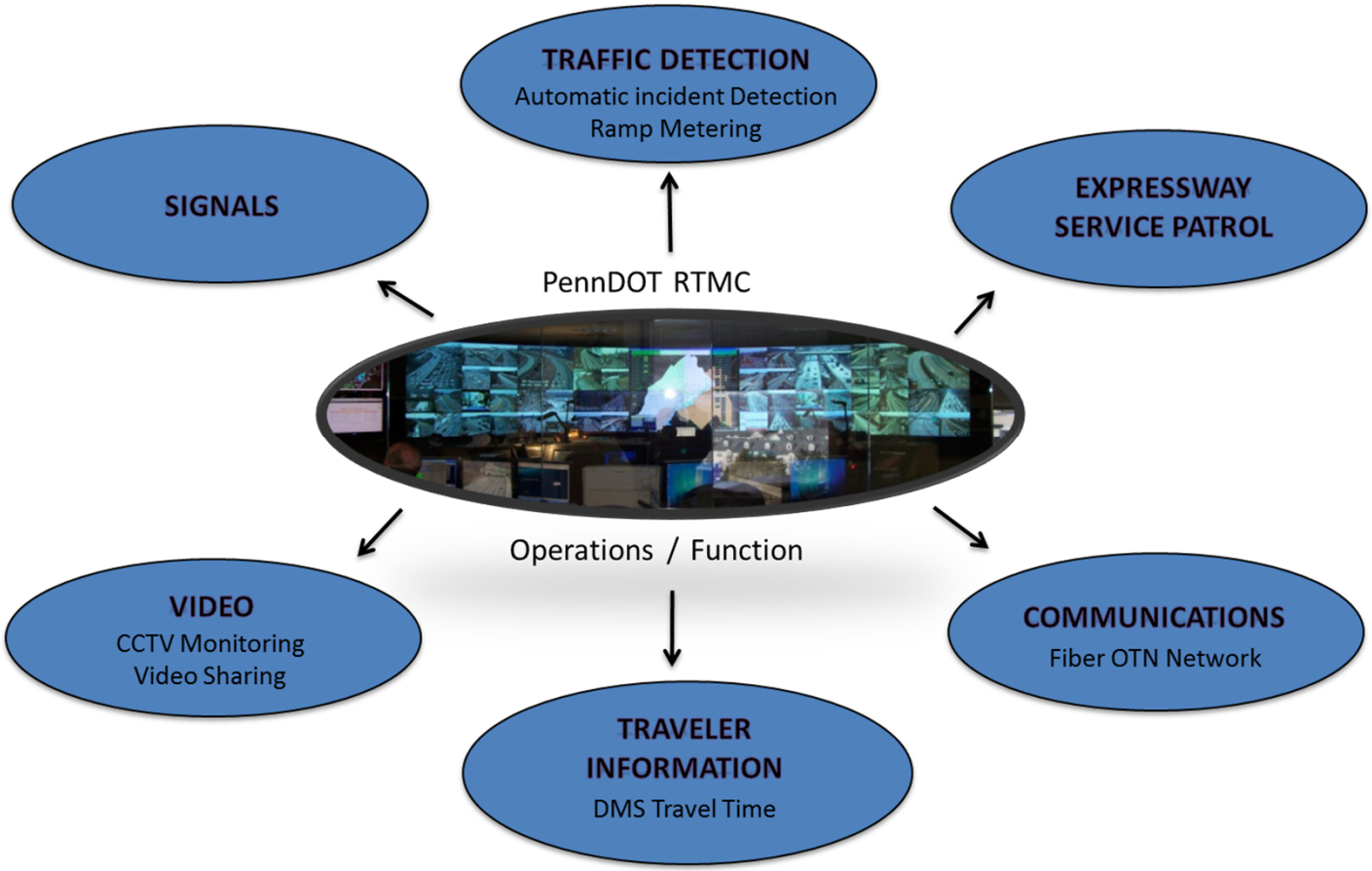
DISTRICT 6-0
TSMO DESIGN AND INTEGRATION GUIDELINES

APRIL 30, 2021

VERSION 1.0

pennsylvania
DEPARTMENT OF TRANSPORTATION

DISTRICT 6-0 TRAFFIC OPERATIONS



PURPOSE AND INTENT

- To serve as a critical reference document when planning, designing, constructing, integrating and testing of TSMO strategies.
- Directed to all involved in design, deployment, and integration of devices:
  - Federal Highway Administration (FHWA)
  - PennDOT Bureau of Infrastructure and Operations (BIO)
  - PennDOT Central Office (BOPD & BOMO)
  - PennDOT District IT & Traffic Operations Staff
  - Design Consultants
  - Contractors
  - Network Integrators
  - Other Key stakeholders (DVRPC, SEPTA, etc….)
- Follow the guidance provided within the document for all phases of a project to mitigate potential delays or coordination issues.
- Does not cover the regional ITS architecture – project designers are expected to evaluate the regional architecture during the systems engineering phase and incorporate changes as necessary.

DOCUMENT LAYOUT

Ch 1 - Introduction

- Document Purpose
- OA Requirements

Ch 2- Design Phase

- Deliverables
- Timeline
- Process
  - ✓Scoping
  - ✓Systems Engineering Process
  - ✓Design Field View Submission
  - ✓Final Plan Submission
  - ✓Final PS&E Submission

Ch 3 - Integration Phase

- ATMS Enhancement Schedule
- Phases
  - ✓Equipment Submittals
  - ✓Integration Requirements and Kick-off Meeting
  - ✓Field Installation/ Physical Construction
  - ✓Final Integration
  - ✓Systems Acceptance Testing
  - ✓Completion

Appendix

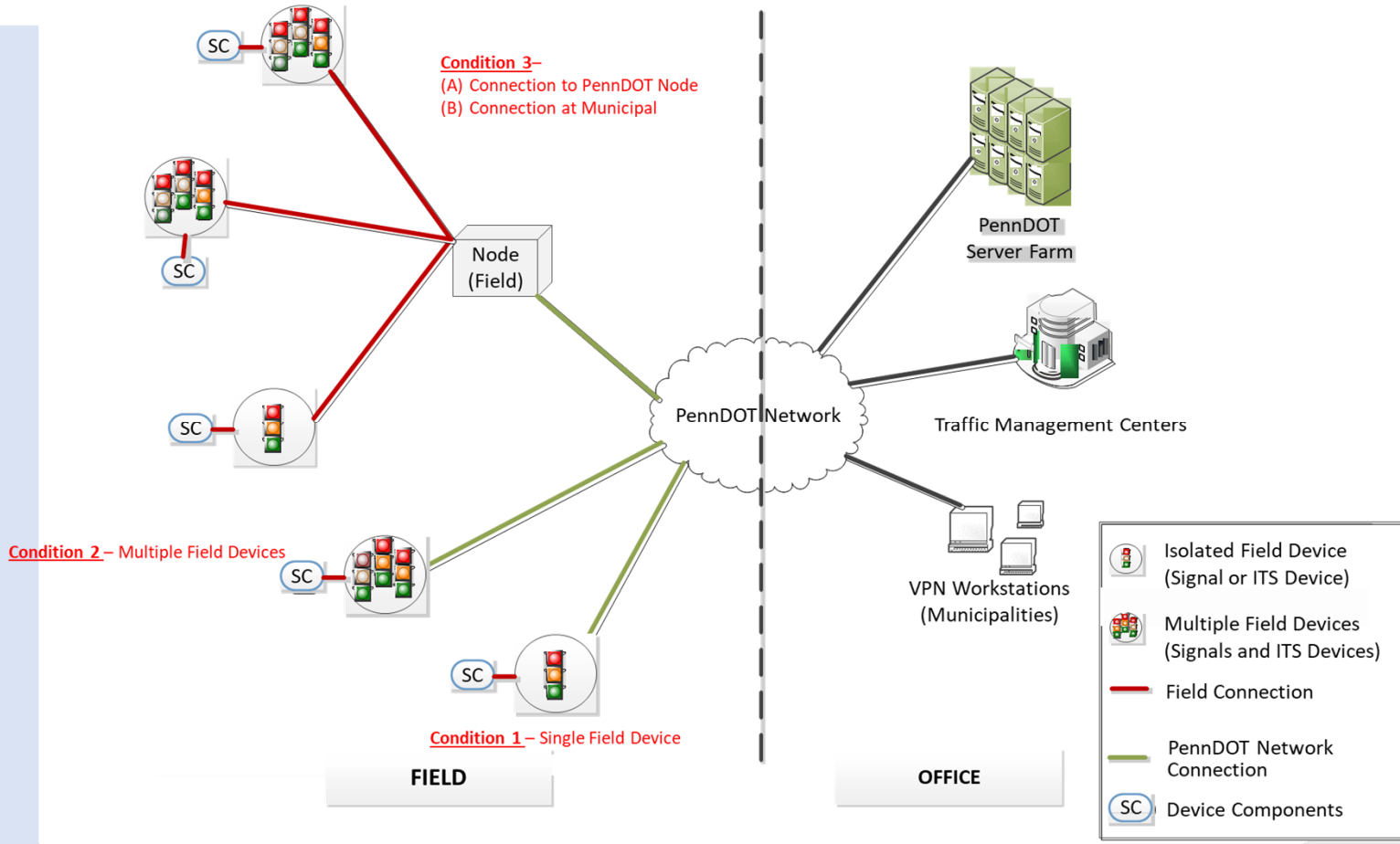
- A – Systems Engineering Report Examples
- B – Travel Time Memo Example
- C – Task H Spreadsheet Template

PENNDOT OA GENERAL GUIDANCE

- No direct Fiber connects into the Commonwealth Network. They need to have networks in place that are capable of connecting directly to COPA over a secure VPN.
- Desired video or other data from outside partners, including municipalities, needs to be brought back to a single headend location. These head ends will be connected to the OA business partner network via a secure VPN.
- Districts should not be purchasing or specifying Cisco 800 Series Routers, other VPN routers, or anything else that relies on connecting devices over the public internet to the Commonwealth Network.
- Existing Cisco 800 Series Routers that have been already purchased and are in the process of being integrated should contact BIO to determine the appropriate solution moving forward.
- Direct connections of field devices (including traffic signals) back to the Commonwealth Network should be on a secure network such as a T1 Line. Cellular devices should not be leveraged for the streaming of video.

NETWORK CONNECTION TYPES

- **Condition 1** is the connection of single isolated field devices back to PennDOT Network
- **Condition 2** is the connection of multiple field devices back from a single field connection back to PennDOT Network
- **Condition 3 (A)** is the connection of multiple field devices back from PennDOT Node device back to the PennDOT Network
- **Condition 3 (B)** is the connection of multiple field devices back to a Municipal Location that will then be sent back to the PennDOT Network through the OA Business Partner Access Point.



DEPLOYMENT OPTIONS

- **Option 1 – PennDOT Owned Equipment and Connecting Back to PennDOT**
  - All Conditions back Permitted
  - PennDOT IT approved ISR Router to connect back to the Commonwealth Network.
  - Commonwealth Network connection through the PennDOT telecom contract.

- **Option 2 – Connecting Municipal owned field devices back to PennDOT Network**
  - Conditions 1 and 2 permitted if a secure T-1 Network Connection can be established. Only permitted if this is the only connection throughout the municipality
  - Condition 3 needs a PennDOT approved ISR Router to Connect back to the PA network.
  - Typically, all Field Devices need to be brought back to a Central Node
  - PennDOT IT approved ISR Router to connect back to the Commonwealth Network.
  - Condition 1 and 2 Connect back through OA's Business Partner Network
  - No direct connection of field network to municipality's network. The municipality must use OA VPN to access field devices.
  - No direct connection or connection of individual field devices back to PennDOT's network.

DEPLOYMENT OPTIONS (CONT.)

- **Option 3- Connecting Municipal owned field devices sent back to the municipality and PennDOT**
  - Condition 3(B) is only permitted.
  - Devices need to be brought back to a Central Municipal Location
  - Design staff will work with PennDOT IT to determine the most appropriate ISR Router to connect back through OA's Business Partner Network
  - No direct connection or connection of individual field devices back to PennDOT's network.

- **Option 4 – Other Connections Not outlined above.**
  - Preliminary coordination and discussion with PennDOT IT is required before finalizing an approach.

PROJECT DEFINITIONS

For the purposes of these guidelines, projects are defined as follows:

Typical ITS System Deployment	New ITS System Deployment	ATMS Modification / Enhancement
• Project with previously established devices to be considered and deployed.	• Project with new TSMO strategies being considered and deployed within the region.	• ATMS platform adjustments.

DESIGN PHASE – DESIGN DELIVERABLES, GENERAL

Phase	Deliverables/Steps	Responsibility	Reviewer	Approval Agency
Scoping	Design Scope/Budget	Designer PennDOT PM	District ITS staff	District ITS staff Central Office FHWA
Systems Engineering Process	Systems Engineering documents See Appendix A for Examples	Designer	District ITS staff Central Office	District ITS staff Central Office FHWA
	30% plans	Designer	District ITS staff	District ITS staff
60%/DFV Submission	Device Locations Staked/Finalized	Designer	District ITS staff	District ITS staff
	Communications/power identified		District ITS staff	District ITS staff
	Utilities identified		District ITS staff	District ITS staff
	Draft quantities and items identified		District ITS staff	District ITS staff
	Proprietary items identified		District ITS staff	Central Office
	Safety report completed		District ITS staff	Central Office
	Environmental clearance documents submitted	District ITS staff Designer to Support	District ITS staff	DEP
	Software modifications or procurements identified	Designer	District ITS staff, Central Office	District ITS staff Central Office

Phase	Deliverables/Steps	Responsibility	Reviewer	Approval Agency
90%/FDOM Submission	Draft Special Provisions	Designer	District ITS staff	District ITS staff Central Office
	Draft Proprietary item letter		District ITS staff Central Office	Central Office FHWA
	Draft bid tabs, item list		District ITS staff	District ITS staff Central Office
	Power and communications details (equipment, wiring, routing, architecture, integration)		District ITS staff Central Office	District ITS staff Central Office
	Utility conflicts identified/resolved		District ITS staff	District ITS staff Central Office
	TS&L approved	Designer	District ITS staff	Central Office
	Draft cost estimate	Designer	District ITS staff	District ITS staff Central Office
	Software modifications or procurements finalized with vendor	Designer	District ITS staff Central Office	Central Office
100%/PS&E	All FDOM comments addressed and included in final bid package	Designer	District ITS staff Central Office	District ITS staff Central Office
	Software modification procurement incorporated into bid package	Designer	Central Office	Central Office
	Proprietary items approved		Central Office	Central Office FHWA
	Bid package uploaded to ECMS	District ITS staff CM	District ITS staff	Central Office
	All required forms, pre-bid schedules, etc. are completed and uploaded to ECMS as needed	Designer and District ITS staff CM	District ITS staff	Central Office

DESIGN PHASE – DESIGN DELIVERABLES, DEVICE-SPECIFIC

Device Type	Phase	Deliverables/Steps	Responsibility	Reviewer	Approval Agency
Travel Time Sensor	60%/DFV Submission	A Travel Time Memo that includes all the travel time links that will be required to post travel time messages onto the project DMS is developed. See Appendix B for Example	Designer	District ITS staff	District ITS staff
	60%/DFV Submission	All potential links need to be evaluated to determine if they will work based on link lengths/spacing, etc.	Designer	District ITS staff Central Office	District ITS staff
	90%/FDOM Submission	Analysis needs to be coordinated to see if the approved travel time links from the travel time memo will be generated via real-time data from the installation of new TTS or if the existing INRIX data has a high enough confidence level that it could be used instead. It should be during this phase that confirmation is received that all roadways needed to create these links are available in the PennDOT GIS database.	Designer	District ITS staff Central Office	District ITS staff Central Office
	100%/PS&E	If TTS will be bid as an item on the project, there needs to be a special provision requiring the contractor to upgrade and integrate links into the BR server	Designer	District ITS staff Central Office	District ITS staff Central Office
DMS	60%/DFV Submission	A DMS message memo, which includes any travel time message and/or special messages (graphics, etc.), is developed to determined what will be posted on each sign in the project.	Designer	District ITS staff	District ITS staff Central Office
CCTV	In general, the design process of CCTVs follows all the steps listed above in Table 1 with no additional deliverables required.				

DESIGN PHASE – TIMELINE

Phase	Minor	Moderate	Complex
Scoping	0-1 Months	1-2 Months	2-4 Months
Systems Engineering	1 Month	1-2 Months	3-6 Months
60% / DFV	3 Months	3-6 Months	3-12 Months
90% / FDOM	2 Months	2-3 Months	3-12 Months
100% PS&E	2 Months	2-3 Months	3-6 Months
TOTAL DESIGN TIME	8-9 Months	9-16+ Months*	14-40+ Months*

Phasing for ITS projects that are a component part of roadway and bridge projects may be subject to the submission schedule of the overall roadway/bridge design.

Minor Project

- Small number of device installations.
- Device types previously deployed (e.g., CCTV, DMS, Vehicle Detection, HAR, RWIS).
- Deviations from design standards not anticipated.
- Requires very little coordination between design disciplines and other projects (i.e., standalone ITS project).

Moderate Project

- 10+ ITS device installations.
- May require minor deviations from design standards.
- Requires relatively straightforward communications and integration elements to be detailed.
- May or may not be part of a moderately complex roadway or bridge project.

Complex Project

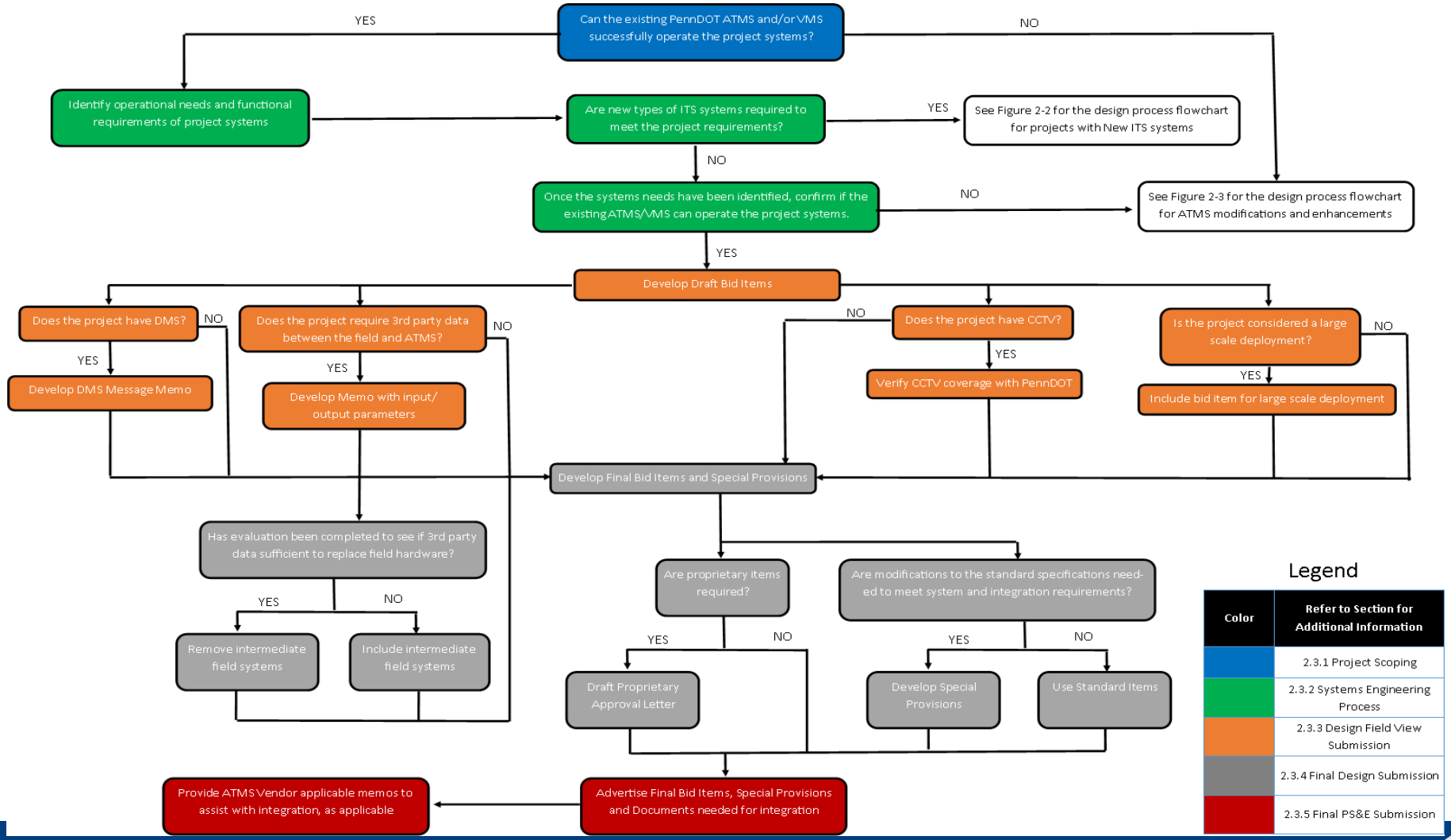
- Large number of ITS device installations.
- Most likely includes new device types and/or systems.
- Significant modifications to design standards are anticipated.
- Requires communications network and TMC integration design elements.
- Device deployments, integration, and testing may be phased and dependent on other aspects of the project.
- May or may not be part of a large roadway or bridge project.
- May or may not require substantial change to or creation of a new software module in ATMS.

DESIGN PHASE – PROCESS

Key Milestones

- Project Scoping
- Systems Engineering Process (30%)
- Design Field View (60%) Submission
- Final Design (90%) Submission
- Final Plans, Specifications, and Estimate (100%) Submission

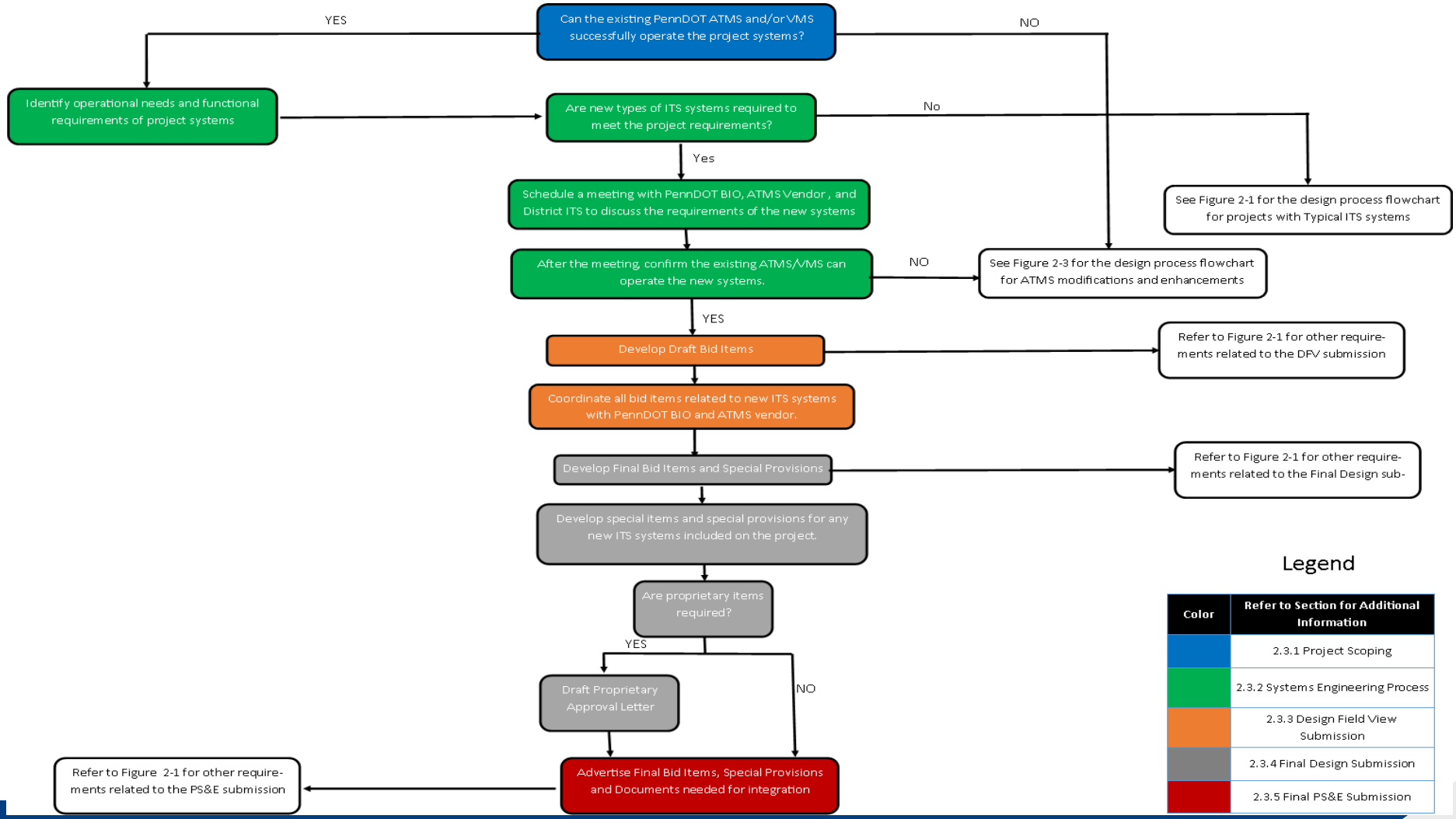
DESIGN PHASE – TYPICAL ITS SYSTEM DEPLOYMENTS



Legend

Color	Refer to Section for Additional Information
	2.3.1 Project Scoping
	2.3.2 Systems Engineering Process
	2.3.3 Design Field View Submission
	2.3.4 Final Design Submission
	2.3.5 Final PS&E Submission

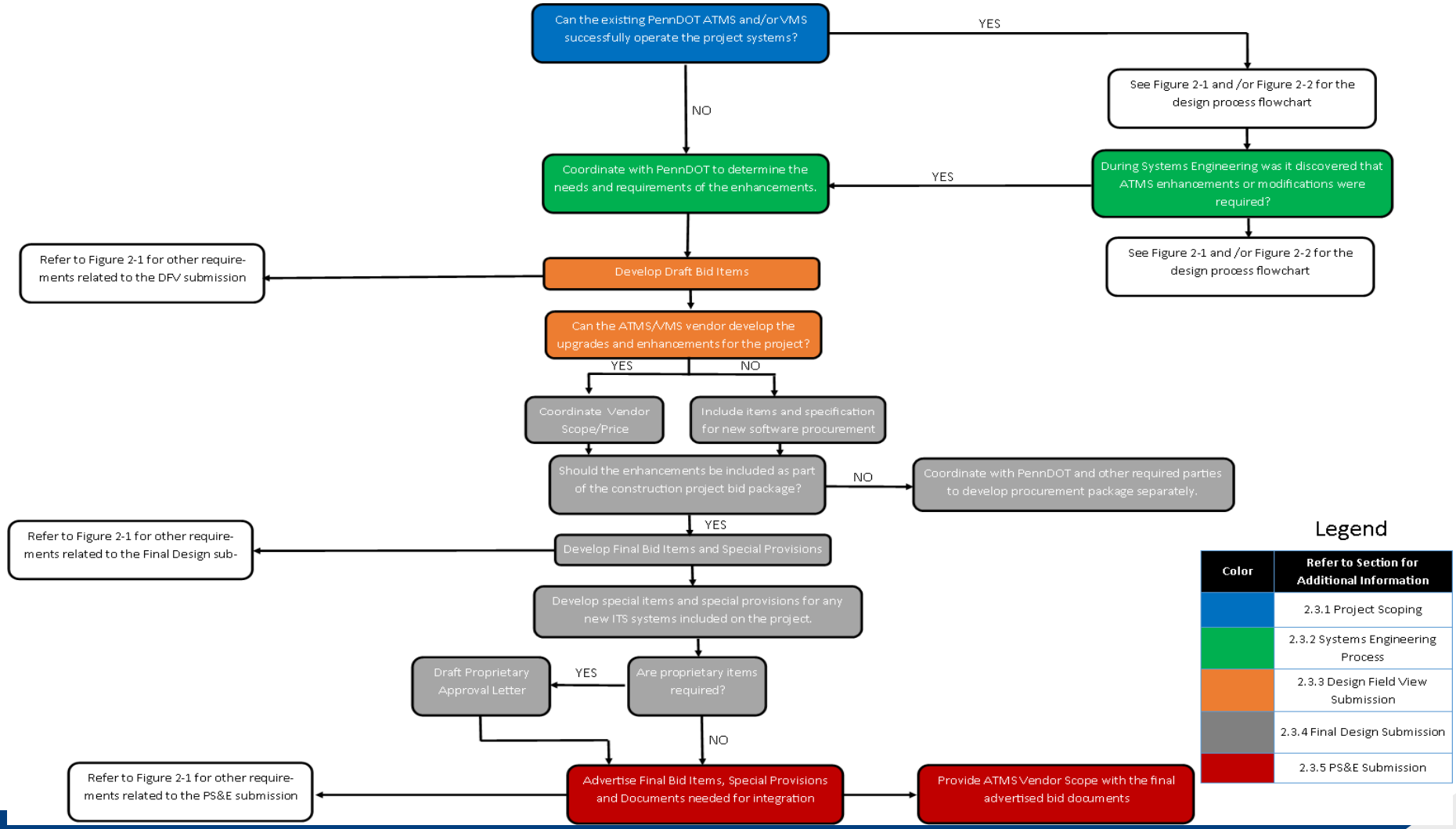
DESIGN PHASE – NEW ITS SYSTEM DEPLOYMENTS



Legend

Color	Refer to Section for Additional Information
	2.3.1 Project Scoping
	2.3.2 Systems Engineering Process
	2.3.3 Design Field View Submission
	2.3.4 Final Design Submission
	2.3.5 Final PS&E Submission

DESIGN PHASE – ATMS MODIFICATIONS / ENHANCEMENTS



Legend

Color	Refer to Section for Additional Information
	2.3.1 Project Scoping
	2.3.2 Systems Engineering Process
	2.3.3 Design Field View Submission
	2.3.4 Final Design Submission
	2.3.5 PS&E Submission

DESIGN EXAMPLES

Typical ITS System Deployment

SR 0422, Section M1B

- *Special Provision Item 5202-0001 ATMS ITS DEVICE INTEGRATION, COORDINATION*

New ITS System Deployment

SR 0076, Section PCC (VSL & Queue Detection)

- *Special Provision Item 5202-0001 ATMS ITS DEVICE INTEGRATION, COORDINATION*
- *Special Provision Item 9000-0030 VARIABLE SPEED LIMIT AND QUEUE WARNING SOFTWARE MODULE*

ATMS Modification / Enhancement

SR 0076, Section ICM

- *Special Provision Item 5202-0001 ATMS ITS DEVICE INTEGRATION, COORDINATION*
- *Special Provision Item 9000-XXXX NEW MODULE 1*
- *Special Provision Item 9000-XXXX NEW MODULE 2 (as needed)*

DESIGN PHASE QUESTIONS

pennsylvania
DEPARTMENT OF TRANSPORTATION

PROJECT DEFINITIONS

For the purposes of these guidelines, projects are defined as follows:

Typical ITS System Deployment	New ITS System Deployment	ATMS Modification / Enhancement
• Project with previously established devices to be considered and deployed.	• Project with new TSMO strategies being considered and deployed within the region.	• ATMS platform adjustments.

INTEGRATION PHASE – ATMS ENHANCEMENT SCHEDULE

Phase	Minor*	Moderate*	Complex*
Submittal Review	3-5 Months	3-6 Months	6-9 Months
Detailed Software Design	N/A	0-3 Months	3-6 Months
Software Development	N/A	0-6 Months	3-12 Months
User Acceptance Testing	N/A	0-1 Month	1-2 Months
Systems Acceptance Testing	1 week -1 Month	1-2 Months	1-3 Months
Operational Testing/Support	5 Months	5-12 Months	12-30 Months

Timelines are not aggregate and may overlap. Overall construction duration may be a function of field installation.

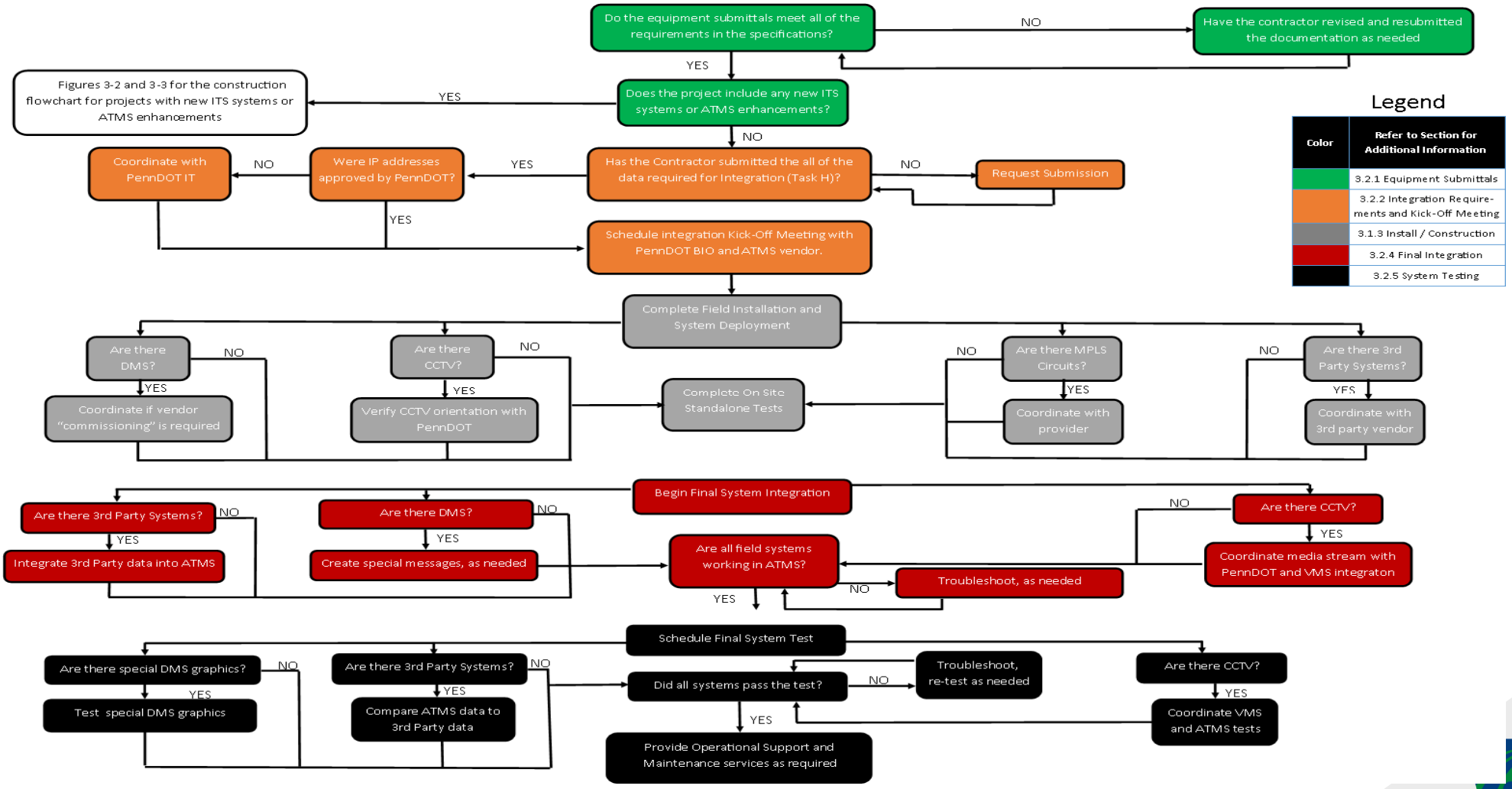
- **Minor** – Enhancements limited to adding a new vendor device into an existing module.
- **Moderate** – Minor modification of an existing module could be required based on updated requirements.
- **Complex** – Development of a new module or a substantial enhancement to an existing module.

INTEGRATION PHASE

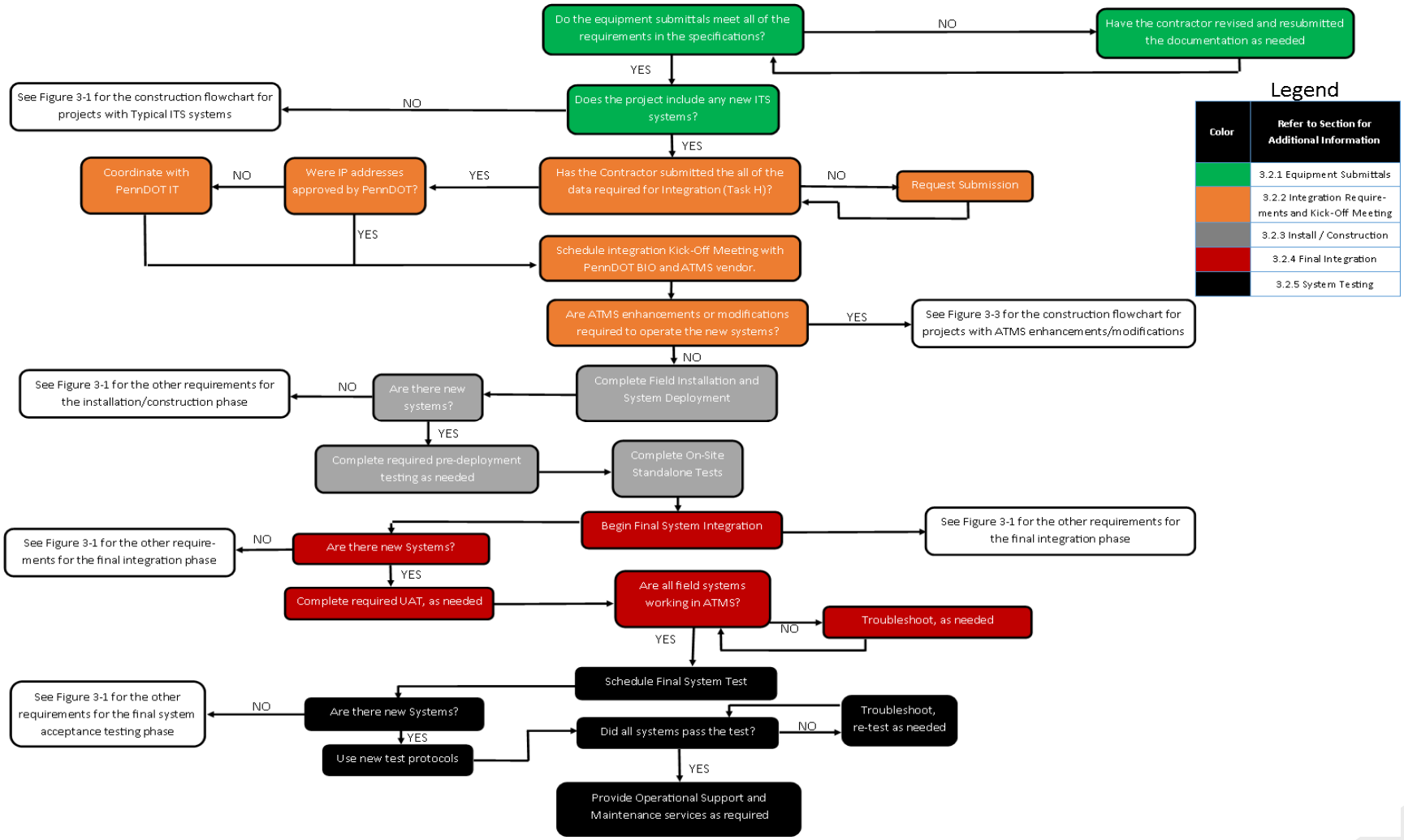
Key Aspects

- Equipment Submittals
- Integration Requirements and Kick-Off Meeting
- Field Installation / Physical Construction
- Final Integration
- System Testing

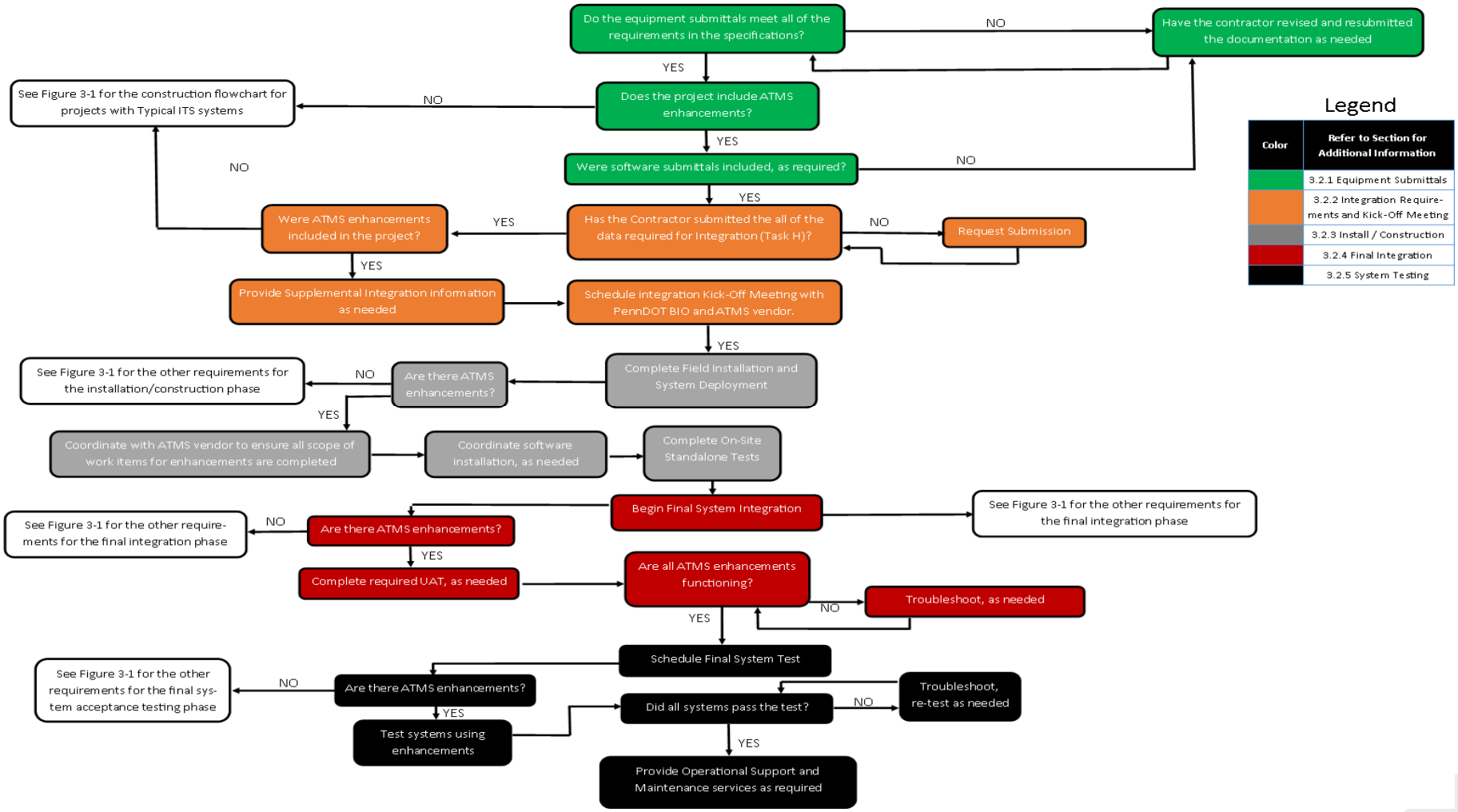
INTEGRATION – TYPICAL ITS DEPLOYMENTS



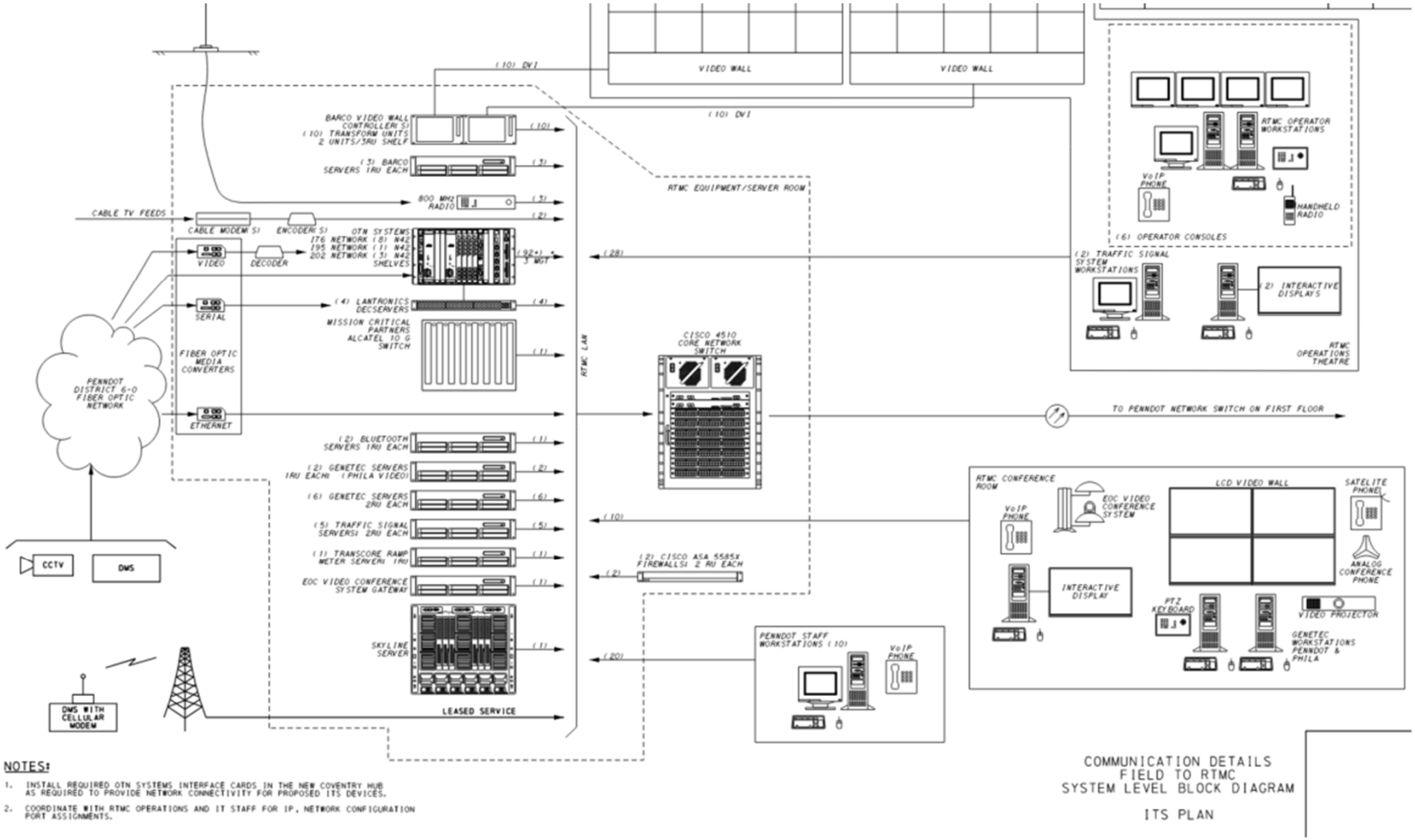
INTEGRATION – NEW ITS DEPLOYMENTS



INTEGRATION – ATMS MODIFICATIONS / ENHANCEMENTS



INTEGRATION - TYPICAL ITS DEPLOYMENTS EXAMPLE
SR 0422, SECTION MIB



NOTES:

1. INSTALL REQUIRED OTN SYSTEMS INTERFACE CARDS IN THE NEW COVENTRY HUB AS REQUIRED TO PROVIDE NETWORK CONNECTIVITY FOR PROPOSED ITS DEVICES.
2. COORDINATE WITH RTMC OPERATIONS AND IT STAFF FOR IP, NETWORK CONFIGURATION PORT ASSIGNMENTS.

COMMUNICATION DETAILS
FIELD TO RTMC
SYSTEM LEVEL BLOCK DIAGRAM

ITS PLAN

INTEGRATION EXAMPLES

Typical ITS System Deployment

SR 0422, Section M1B

- *Factory Test generally waived in lieu of factory certification*
- *On-Site Test performed by Contractor – Witnessed by PennDOT*
- *System Acceptance Test performed by RTMC with support from ATMS Vendor and Contractor*

New ITS System Deployment

SR 0076, Section PCC (VSL & Queue Detection)

- *Factory Test generally waived for previously deployed device types in lieu of factory certification*
- *Factory Test may be required for new systems (to be determined during System Engineering process)*
- *On-Site Test performed by Contractor – Witnessed by PennDOT*
- *Software-Specific Testing conducted by ATMS Vendor – Witnessed by PennDOT*
- *System Acceptance Test for previously deployed device types performed by RTMC with support from ATMS Vendor and Contractor*
- *System Acceptance Test for new systems performed by New System Vendor or ATMS Vendor with support from Contractor*

ATMS Modification / Enhancement

SR 0076, Section ICM

- *Factory Test generally waived for previously deployed device types in lieu of factory certification*
- *Factory Test may be required for new systems (to be determined during System Engineering process)*
- *On-Site Test performed by Contractor – Witnessed by PennDOT*
- *Software-Specific Testing conducted by ATMS Vendor – Witnessed by PennDOT*
- *System Acceptance Test for previously deployed device types performed by RTMC with support from ATMS Vendor and Contractor*
- *System Acceptance Test performed by ATMS Vendor with support from Contractor*

INTEGRATION PHASE QUESTIONS

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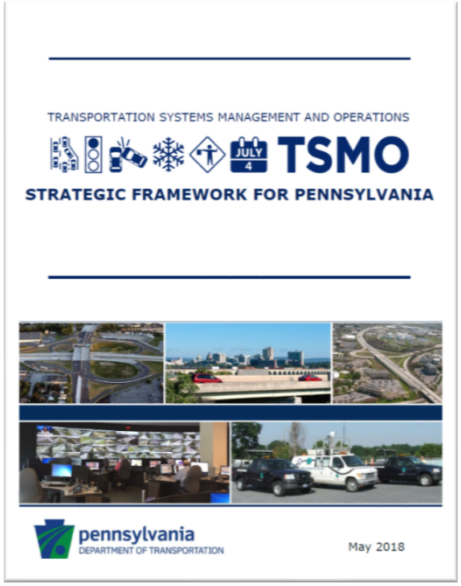
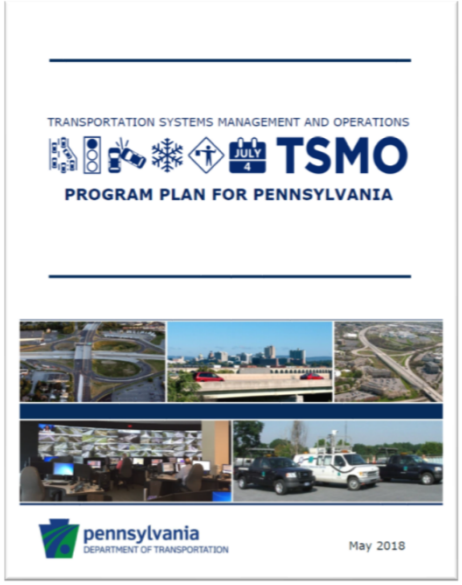
APPENDICES

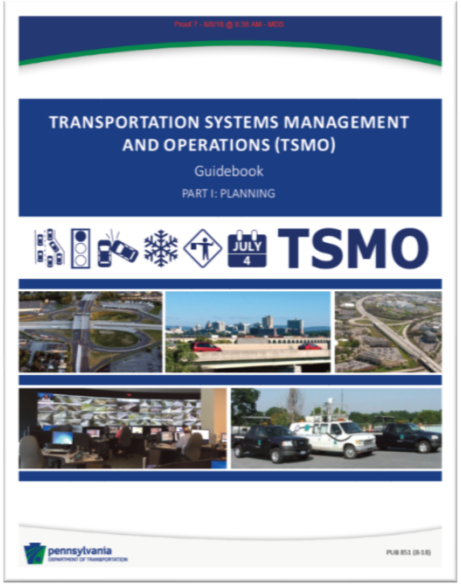
- **Appendix A** – Systems Engineering Report Examples
  - Typical ITS Project – SR 0422, Section M1B
  - Complex ITS Project – I-76 ITS Enhancements
- **Appendix B** – Travel Time Memo Example
- **Appendix C** – Task H Spreadsheet Template

TSMO Key Deliverables

Vision	Approach	Policy
Strategic Framework	Program Plan	Guidebook Series







https://www.penndot.gov/ProjectAndPrograms/operations/Pages/default.aspx

www.penndot.gov (TSMO)

TSMO

TSMO Guidebook Series

Part I: Planning	Part II: Design	Part III: Construction	Part IV: Maintenance	Part V: Operations
Pub 851	Pub 852	Pub 853	Pub 854	Pub 855
• ROPs • Metrics • TSMO Toolbox	• Design standards for each TSMO Toolbox strategy • Incorporates, updates and combines Pub 646 ITS Design Guide, and Pub 647 ITS Civil & Structural Standards • Future Incorporation of this Guidance	• Construction standards • May just be references to Pub 408	• Maintenance requirements • Maintenance contracting • Incorporates and updates Pub 697 ITS Maintenance Standards	• Traffic Operations Program Overview • Traffic Operations Policies and Procedures

TSMO

NEXT STEPS

- Initially intended for District 6-0 only
- To be expanded for all PennDOT Districts

QUESTIONS

PennDOT TSMO Website

https://www.penndot.gov/ProjectAndPrograms/operations/Pages/default.aspx

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