I-76 Multi-Modal Integrated Corridor Initiative

Advanced Transportation and Congestion Management Technologies Deployment Initiative (ATCMTD)

Vol. 1 Technical Application

pennsylvania
DEPARTMENT OF TRANSPORTATION

SEPTA

SEAL OF THE CITY OF PHILADELPHIA

Advanced Transportation and Congestion Management Technologies Deployment Initiative (ATCMTD)

Project Name	I-76 Multi-Modal Integrated Corridor Initiative
Eligible Entity Applying to Receive Federal Funding	The Pennsylvania Department of Transportation (PennDOT)
Total Project Cost (from all sources)	$10.4 Million
ATCMTD Request	$5.2 Million
Are matching funds restricted to a specific project component? If so, which one?	No. Matching funds are not restricted to a specific component.
State(s) in which the project is located.	The Commonwealth of Pennsylvania
Is the project currently programmed in the: Transportation Improvement Program (TIP) Statewide Transportation Improvement Program (STIP) MPO Long Range Transportation Plan State Long Range Transportation Plan	 No No No No
Technologies Proposed to be deployed (briefly list)	I-76 Integrated Corridor Management Decision Support Software • Planning and Development of decision support software Henry Avenue Corridor TSMO • CCTV • Bluetooth Readers • Travel Time System • Arterial Dynamic Message Signs • Transit Signal Priority

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Executive Summary

The Pennsylvania Department of Transportation District 6-0 submits the following application for consideration for the Advanced Transportation and Congestion Management Technologies Deployment initiative. The following application will advance the region's vision for a multi-modal smart corridor that improves traffic flow and safety by integrating the region's Advanced Transportation Management infrastructure in addition to deploying new infrastructure.

1. Introduction

The Pennsylvania Department of Transportation District 6-0 is submitting the following application to the Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Grant program to forward its I-76 Integrated Corridor Management (ICM) efforts. The following application requests funds to develop decision support software to manage its Active Traffic Management (ATM) devices along I-76 and install multi-modal ATM devices along Henry Avenue, one of the parallel arterials that will be integrated into the I-76 ICM system. PennDOT will evaluate before and after traffic operations and safety improvements for the I-76 corridor and deploy the software and similar ATM strategies along other critical corridors in the region.

The software component of the project is critical to manage and optimize the existing and future ATM devices. To improve traffic flow and safety along the I-76 corridor, PennDOT, the City of Philadelphia, the Southeastern Pennsylvania Transportation Authority (SEPTA) and the Delaware Valley Planning Commission (DVRPC) have joined together and programmed seven projects to deploy the following ATM strategies:

- Traffic Signal Coordination along parallel corridors in Montgomery and Philadelphia Counties
- Dynamic Signal Management
- Variable Speed Limits
- Queue Detection
- Ramp Metering
- Junction Control
- Part-Time Shoulder Use
- Smart Parking and SEPTA regional rail service information displayed on DMS signs

To optimize these ATM devices and establish an integrated corridor, a decision support software needs to be developed for PennDOT to have a fully integrated and optimized system that is able to distribute travel information to travelers and to effectively manage traffic patterns and behaviors.

As part of its corridor integration program, PennDOT is taking over the signals along arterials parallel to I-76; one of these corridors is Henry Avenue located in northwest Philadelphia. There is currently a project programmed to upgrade the signals along the corridor so that they can be integrated and actively managed by PennDOT's Regional Traffic Management Center (RTMC). With this grant opportunity, PennDOT, the City of Philadelphia and SEPTA could augment the existing scope of work to include the following ATM devices:

- Bluetooth Readers
- DMS Signs
- CCTV Cameras
- Transit Signal Priority for Bus Route 27

The Henry Avenue TSMO project will increase the City of Philadelphia and SEPTA's Transit Signal Priority system and provide a more reliable alternative mode of transportation.

Funding through the ATCMTD Initiative will allow PennDOT and its partners to optimize the region's ATM infrastructure to increase safety, improve traffic operations, and provide more transportation choices for all its users for an interstate that cannot be widened due to environmental and land use constraints.

2. Background

2.1. PennDOT District 6-0

PennDOT will be the entity entering into an agreement with FHWA for the ATCMTD program; PennDOT District 6-0 will manage the design and construction of the project locally. The City of Philadelphia and SEPTA are key stakeholders for the Henry Avenue TSMO device deployment project and will be engaged during design and construction to ensure that the devices are deployed properly.

PennDOT District 6-0 is responsible for maintaining the Federal and State highway infrastructure in Bucks, Chester, Delaware, Montgomery and Philadelphia Counties and operates the largest transportation infrastructure network in the Commonwealth of Pennsylvania. Over the past Federal fiscal year, District 6-0 let a total of $ 408.6 million; the largest three federal aid highway projects and their project values are listed below.

- I-95, Section BS4 $81,022,883
- SR 322 Section 101 $62,644,460
- SR 202 Section 3RR $26,370,555

PennDOT District 6-0 has also been an active partner in assisting the City of Philadelphia with three of its multi-modal TIGER programs. The TIGER III program involved the City of Philadelphia, SEPTA and PennDOT District 6-0 to successfully deploy Transit Signal Priority along two corridors located in the City of Philadelphia. The total program cost was $17.5 million and was successfully constructed as per the requirements of the TIGER III program.

PennDOT is a good steward of federal funds and District 6-0's Assistant District Executive of Design, Charles H. Davies, P.E., will be taking main management responsibility for the program. If awarded the funds, the project will be programmed by PennDOT Central Office and the Regional MPO on the current 2017 Transportation Improvement Plan (TIP), The project will be by District 6-0's Traffic Unit and the Project Manager. More information regarding the organization management of the program is included as Figure 8 and Table 4 and discussed further in Section 6. Partnering Plan.

2.2. Description of the Area

PennDOT District 6-0 operates and maintains surface highway infrastructure for the Nation's 6th largest metropolitan area. Although the population of Philadelphia decreased during the 1980's with the decline of US manufacturing, it has recently experienced growth in the last 20 years and is having difficulty meeting housing demands. The City of Philadelphia skyline is rapidly developing to provide housing for new residents and office space for companies who are now calling Philadelphia home. This also applies to the surrounding suburban counties of Buck, Chester, Delaware and Montgomery that have seen an increase in development with the rise of the pharmaceutical industry within the region.

Problem Statement

Located between the Schuylkill River and a steep rock face, it is not economically feasible nor environmentally prudent to construct a capacity-adding project for I-76. Over the past 20 years, PennDOT, DVPRC and the City of Philadelphia have developed a mature ITS system to increase traffic operations and safety. Implementing a multi-modal integrated corridor management system operated by decision support software is the next step in improving traffic operations for an interstate that cannot be widened.

2.3. Issues

To support the traffic demands to its system is difficult as PennDOT District 6-0 maintains and operates the highway system for one of the oldest metropolitan areas in our Nation. Existing land use development patterns and environmental constraints make it challenging to program and construct large capacity infrastructure programs to support this growing region.

The most constrained interstate in District 6-0's system is I-76. Since the completion of the Interstate in 1960, it was clear that the design year Average Annual Daily Traffic (AADT) of 35,000 vehicles per day (VPD) would be exceeded. By 1970, the ADDT's increased to 80,000 VPD and as of today, mainline traffic volumes exceed 115,000 VPD. As a result traffic operations along the corridor are failing.

Figure—1 I-76 and Route 1 Interchange

Figure—2 I-76 and to Center City Philadelphia

Crash Analysis conducted for the 13 mile stretch of the corridor between the King of Prussia Interchange to US 1 are high also. Many of the crashes are attributed to poor traffic operations;

- 30% of the corridor has a crash rate exceeding 200% of the statewide average.
- 44% of the corridor experienced rear-end crashes at more than double the statewide average
- High-impact, low frequency crashes average 1 per month

Widening the interstate to meet these demands is not feasible. Nestled between the Schuylkill River, and a steep slope of bedrock, widening I-76 between King of Prussia and US 1 presents many challenges. A host of alternatives such as stacking a second deck over the existing interstate, to building a second structure along the river have been considered, but none of these alternatives were economically feasible and they presented several environmental impacts and challenges.

Improving traffic operations along I-76 is critical as it provides a direct connection to King of Prussia, the Nation's largest retail center, and to the City of Philadelphia. It also is a part of a larger infrastructure network that supports a regional economy with an estimated gross domestic product of $388 billion. I-76 connects to other critical interstates such as I-676, I-95 and I-476, in addition to other highway systems such as the Pennsylvania Turnpike and therefore poor operations along I-76 have an impact to the regional and national economy.

To address these traffic operation challenges along the I-76 corridor, PennDOT District 6-0 prepared an *I-76 ITS Enhancement Conceptual Operations Report* to leverage the ITS investment it has made over the past 20 years and in addition to guiding its future ITS/ATM strategies. After analyzing the existing operations of the corridor and input from key stakeholders and users, the report recommended implementing a multi-modal ICM program for I-76 that would improve traffic flow along this constrained corridor and leverage the transit opportunities along the corridor. While these recommendations are being implemented, PennDOT needs a decision support software in addition to deploying more multi-modal ATM devices to augment its system to maximize the benefit from these technologies.

3. Progressing Forward

3.1. PennDOT's Vision

At a press conference held on September 27, 2016, PennDOT Secretary of Transportation, Secretary Richards expressed PennDOT's vision for a multi-modal Integrated Corridor Management system on I-76 to provide more reliable transportation options given that additional capacity cannot be built along this interstate corridor.

PennDOT's ICM Vision for I-76 Corridor

"This corridorwide, multi-agency, multi-modal approach is the optimal strategy to address the I-76 corridor, now and into the future. We believe this combination of real-time traffic management, more frequent transit service and improvement of signal systems on adjacent arterials roads will collectively make this corridor a smoother one for everyone to travel on."

Secretary Leslie Richards
Commonwealth of Pennsylvania

The proposed multi-modal ICM strategy would optimize the existing network by deploying the following ATM strategies that are programmed over the course of the next two DVRPC TIP cycles (Table 1 and Figure 3). The effort is a multi-agency and multi-municipality effort that PennDOT believes will ensure greater mobility along the corridor without having to program a large capacity-adding project. The Multi-Modal Integrated Corridor Management strategy for the I-76 corridor between the King of Prussia to the City of Philadelphia involves the following ATM Strategies:

- Traffic Signal Coordination along parallel corridors in Montgomery and Philadelphia Counties
- Dynamic Signal Management
- Variable Speed Limits
- Queue Detection
- Ramp Metering
- Junction Control
- Part-Time Shoulder Use
- Smart Parking and SEPTA regional rail service information displayed on DMS signs

3.2. Transportation Systems and Services - Currently Programmed Projects

The following is a brief description of the projects and the ATM devices that will be implemented in the next 3-6 years. (See Figure 3 and Table 1) This devices will be leveraged to create an integrated multi-modal corridor that will require decision making software to manage the devices to truly optimize the corridor benefits and maximize synergies.

I-76 Parallel Arterial Signal Systems - Montgomery and Philadelphia County

PennDOT has identified 154 traffic signals along several arterials parallel to I-76 in Montgomery and Philadelphia County that would improve mobility if integrated and actively managed by PennDOT (See Figure 4). DVRPC and PennDOT have programmed two projects, one for each county, to upgrade the signals and integrate them to PennDOT's RTMC so that they can be actively managed to work in conjunction with the other ATM devices that PennDOT is deploying along the main corridor.

Both projects are anticipated to be completed by 2019 and are critical in deploying other ATM strategies such as Junction Control and Ramp Metering.

Henry Avenue Congested Corridor Phases 1 & 2

As part of FHWA's Highway Safety Improvement Program (HSIP), PennDOT is upgrading the signals and ADA ramps, replacing guiderail, and improving traffic signs along Henry Avenue between Ridge Pike and US 1. The purpose of the project is to improve traffic safety and mobility along the corridor in addition to upgrading the signals so that PennDOT can actively manage them as part of the I-76 Parallel Arterial Signal System effort.

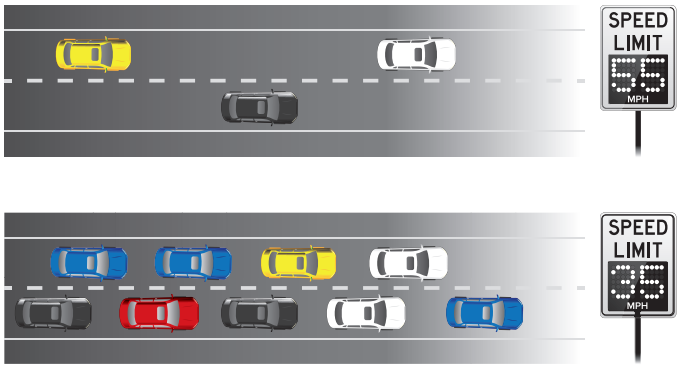
Phase 1, located between Port Royal Avenue and West School House Lane, will be completed by 2018. Phase 2, located between Hermit Street and Abbotsford Avenue, will be completed 2019. (Figure 3)

I-76 Regional Travel Information Project

PennDOT DIstrict 6-0 is currently in the final design phase of the I-76 Integrated Corridor Management project which will deploy Variable Speed Limit (VSL) signs and a queue detection / warning system along the entire 13-mile corridor in Montgomery County. Also included in this project is the installation of DMS signs and fiber to augment ITS connections to the RTMC and provide information to the traveling public.

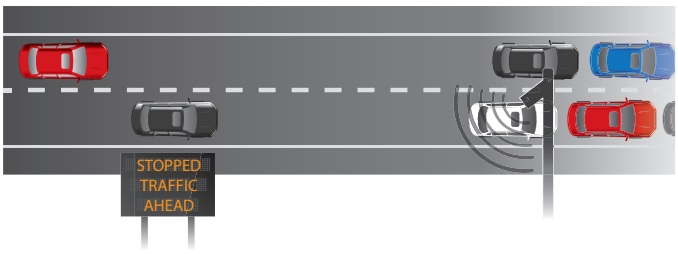
The project is anticipated to be completed by 2019 and will advance PennDOT's goal of improving traffic operations and safety along the I-76 corridor.

VARIABLE SPEED LIMIT (VSL) SIGNS



Once completed, VSLs will replace static speed limit signs on mainline I-76 and will dynamically change the speed limit based on prevailing traffic and weather conditions. The RTMC will monitor these conditions and will set the VSLs to better manage congestion and reduce crashes by displaying the optimal speed that will help traffic move efficiently and safely.

QUEUE DETECTION / WARNING



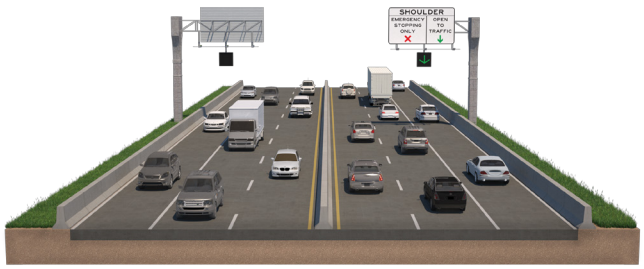
The primary goal of the queue detection and warning system is to reduce the number of rear-end crashes by alerting motorists that stopped vehicles are ahead, prompting drivers to slow down and be alert for traffic stoppages. This system will use vehicle detection technologies already deployed along I-76 to identify vehicle backups, and automatically post messages to existing and new electronic message signs to alert motorists in real time.

I-76 Integrated Corridor Management

For the I-76 Corridor between the PA Turnpike and US 1, PennDOT has programmed a project to implement Ramp Metering, Dynamic Junction Control, Part-Time Shoulder Use and connections to SEPTA's Smart Parking Facility in Conshohocken and future Smart Facilities. Associated with these projects are a number of bridge repair / rehabilitation projects to ensure that the structures over I-76 are wide enough to accommodate Part-Time Shoulder Use.

It is anticipated that the project will be in construction in Summer of 2024 and completed in Spring of 2027.

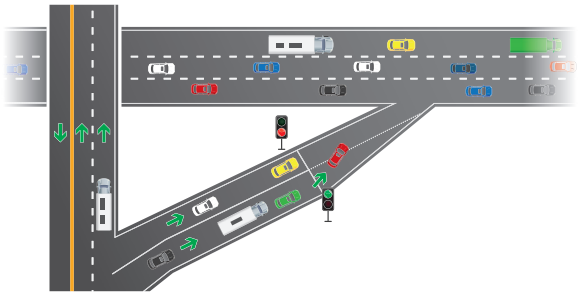
PART-TIME SHOULDER USE



Since widening the I-76 corridor is not feasible, PennDOT is proposing to implement Part-Time Shoulder Use which increases the roadway capacity during peak period by opening up the shoulders for traffic. By allowing vehicles to use the shoulder as a travel lane during congested periods, it is estimated that there will be an additional 1,650 vehicles an hour in roadway throughput is possible. Shoulders are opened and closed through the use of overhead lane use signs will be controlled from PennDOT's RTMC.

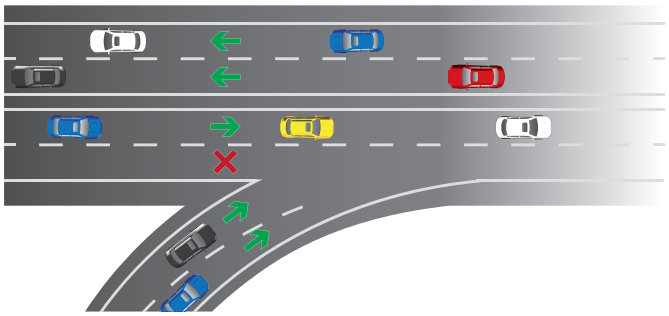
Part-Time Shoulder Use is currently in place in 16 states across the United States. PennDOT plans a deployment on I-76 between the PA Turnpike and I-476.

RAMP METERING



Ramp Metering controls the rates that vehicles can enter a highway via a traffic signal located near the end of the entrance ramp. The intent of Ramp Metering is two-fold. First, to utilize storage space provided by the ramp to provide priority movement to vehicles passing by the interchange. Secondly, to enhance safety by smoothing out the rate at which vehicles merge into mainline traffic, leading to less stop-and- start driving.

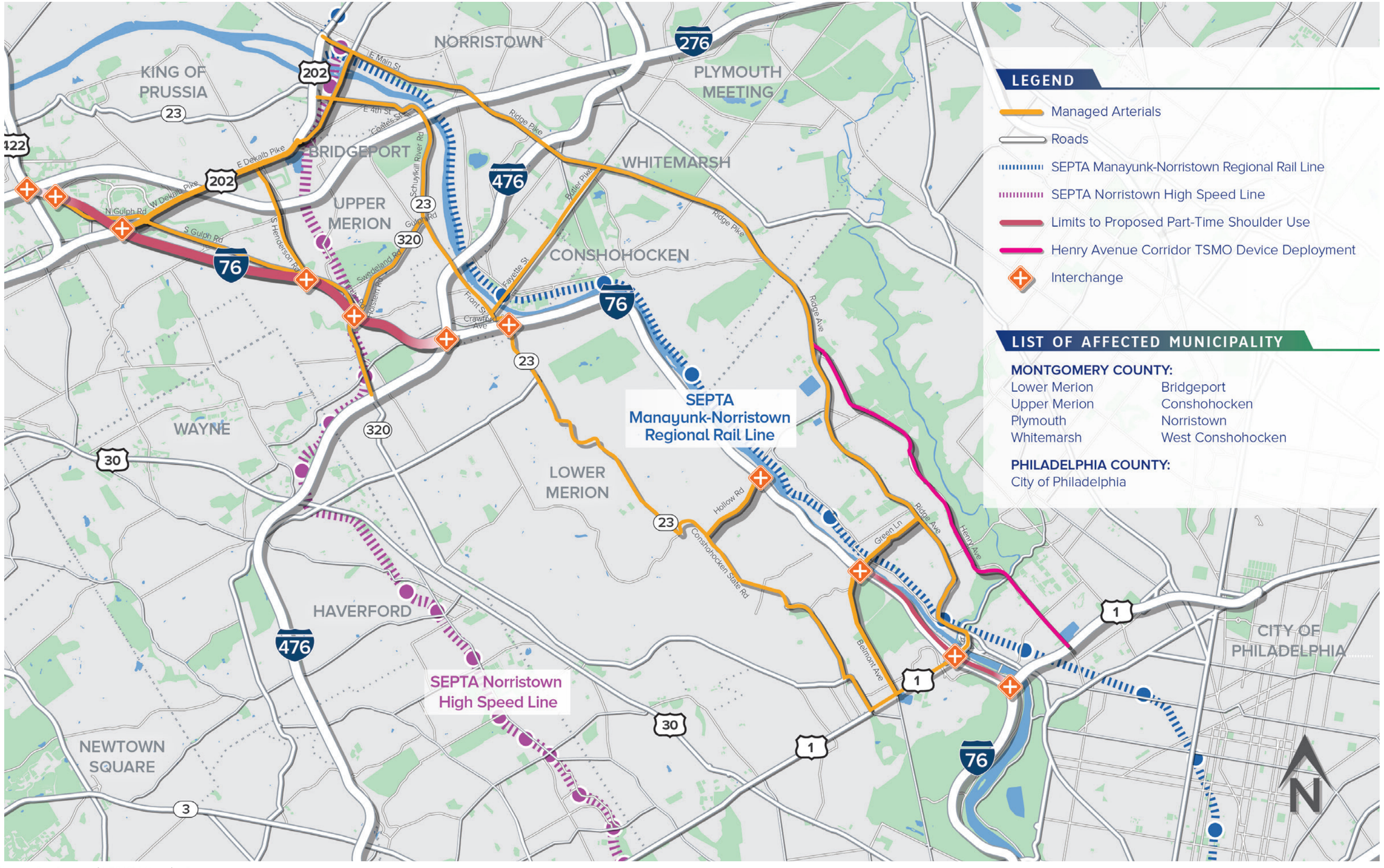
DYNAMIC JUNCTION CONTROL



Dynamic Junction Control uses overhead lane-use signals to control access to both mainline and ramp lanes at interchanges. The intent is to allocate roadway space that favors the highest volume move in a way that can change in response to traffic conditions.

Dynamic Junction Control is currently being evaluated for implementation at interchanges that have an imbalance between merging and through traffic volumes. These interchanges include I-76/U.S. 1; I-76/I-476; and I-76/ U.S.202/U.S. 422.

It is anticipated to improve traffic flow and reduce the number of crashes at interchanges.



LEGEND

- Managed Arterials
- Roads
- SEPTA Manayunk-Norristown Regional Rail Line
- SEPTA Norristown High Speed Line
- Limits to Proposed Part-Time Shoulder Use
- Henry Avenue Corridor TSMO Device Deployment
- Interchange

LIST OF AFFECTED MUNICIPALITY

MONTGOMERY COUNTY:

Lower Merion
Upper Merion
Plymouth
Whitemarsh
Bridgeport
Conshohocken
Norristown
West Conshohocken

PHILADELPHIA COUNTY:

City of Philadelphia

Figure—3 Proposed I-76 ICM Corridor Project

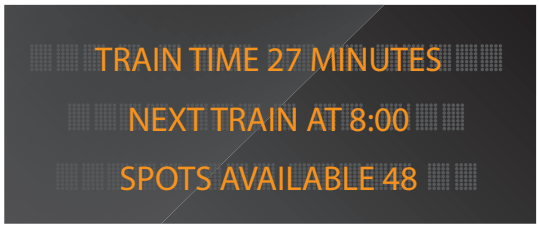
I-76 Multi-Modal Intergrated Corridor Initiative

I-76 Corridor Related Projects

Name of Project	Project Limits	Project Scope	Funding Type	Fund Amount	Estimated Completion Date
CURRENTLY PROGRAMMED PROJECTS					
I-76 Parallel Arterial Signal Systems - Montgomery County	100 signals along parallel corridors in Montgomery County	Pilot project for upgrade of 100 signals tied to RTMC; owned, maintained and operated by PennDOT	State	$10,000,000	2019
I-76 Parallel Arterial Signal Systems - Philadelphia County	54 signals along parallel corridors in Philadelphia County	Pilot project for upgrade of 54 signals tied to RTMC; owned, maintained and operated by PennDOT	State	$10,000,000	2019
Henry Avenue Congested Corridor Phase 1	Port Royal Avenue to West School House Lane	Upgrading signals and ADA Ramps Replacing guiderail	Federal	$8,250,000	2018
Henry Avenue Congested Corridor Phase 2	Hermit Street to Abbotsford Avenue	Upgrading signals and ADA Ramps Replacing guiderail	Federal	$3,000,000	2019
I-76 Regional Traffic Information	13 miles of I-76	Variable Speed Limit (VSL) Signs Queue Detection System	Federal	$3,000,000	2019
I-76 Intergrated Corridor Management	13 miles of I-76	Part-Time Shoulder Use Ramp Metering Junction Control Multimodal Connections	Federal	$13,000,000	Construction anticipated 2020 to 2022
SEPTA Conshohocken Station Upgrades & Garage/Smart Parking	Conshohocken Station	Station improvements & new smart garage tied to PennDOT RTMC	SEPTA Funds		2020
PROPOSED PROJECTS					
Integrated Corridor Management Decision Support System	13 miles of I-76 corridor	Integrating interstate and arterial systems into a Decision Support System	ACTMD grant / State	$7,400,000	48 months from grant award
Henry Avenue TSMO Device Deployment	Henry Avenue from Port Royal Avenue and to Abbotsford Avenue	Transit Signal Priority CCTV DMS Travel Time Systems	ACTMD grant / State	$3,000,000	36 months from grant award

Table—1 I-76 Corridor Related Projects

MULTI-MODAL CONNECTIONS



SEPTA Conshohocken Station Upgrades & Garage / Smart Parking

PennDOT is partnering with SEPTA and other regional transportation agencies to promote transit along the corridor. Along the Schuylkill Expressway Corridor there are the following transit options in addition to numerous bus routes:

- Manayunk / Norristown Regional Rail Line
- Paoli/Thorndale Regional Rail Line
- Norristown High Speed Line

At the stations, there is a combined total of 965 parking spaces that PennDOT and SEPTA would like to optimize. To support this effort, SEPTA has already improved Regional Rail Service times to the Norristown Station and is proposing to integrate vehicle location and smart parking data at the Conshohocken Station. If successful at this location, other regional rail stations located near interstate corridors will provide this information to PennDOT's traveler information systems to notify motorists of transit opportunities via DMS signs and the 511PA.

The SEPTA Conshohocken Station Smart Parking lot will be incorporated into the PennDOT Integrated Corridor Management Project when it is open for traffic in 2027.

It is anticipated that this information would give motorists the opportunity to get off of I-76 to use the other modes of transportation to arrive at their ultimate destination.

With these projects programmed and being deployed along the corridor in the next 6 years, PennDOT recognizes that it needs a decision support software to optimize its ATM corridor along with deploying additional multi-modal ATM strategies along the parallel corridors so that it may realize its vision for a Multi-Modal Integrated Corridor.

3.3. The Opportunity of ATCMTD

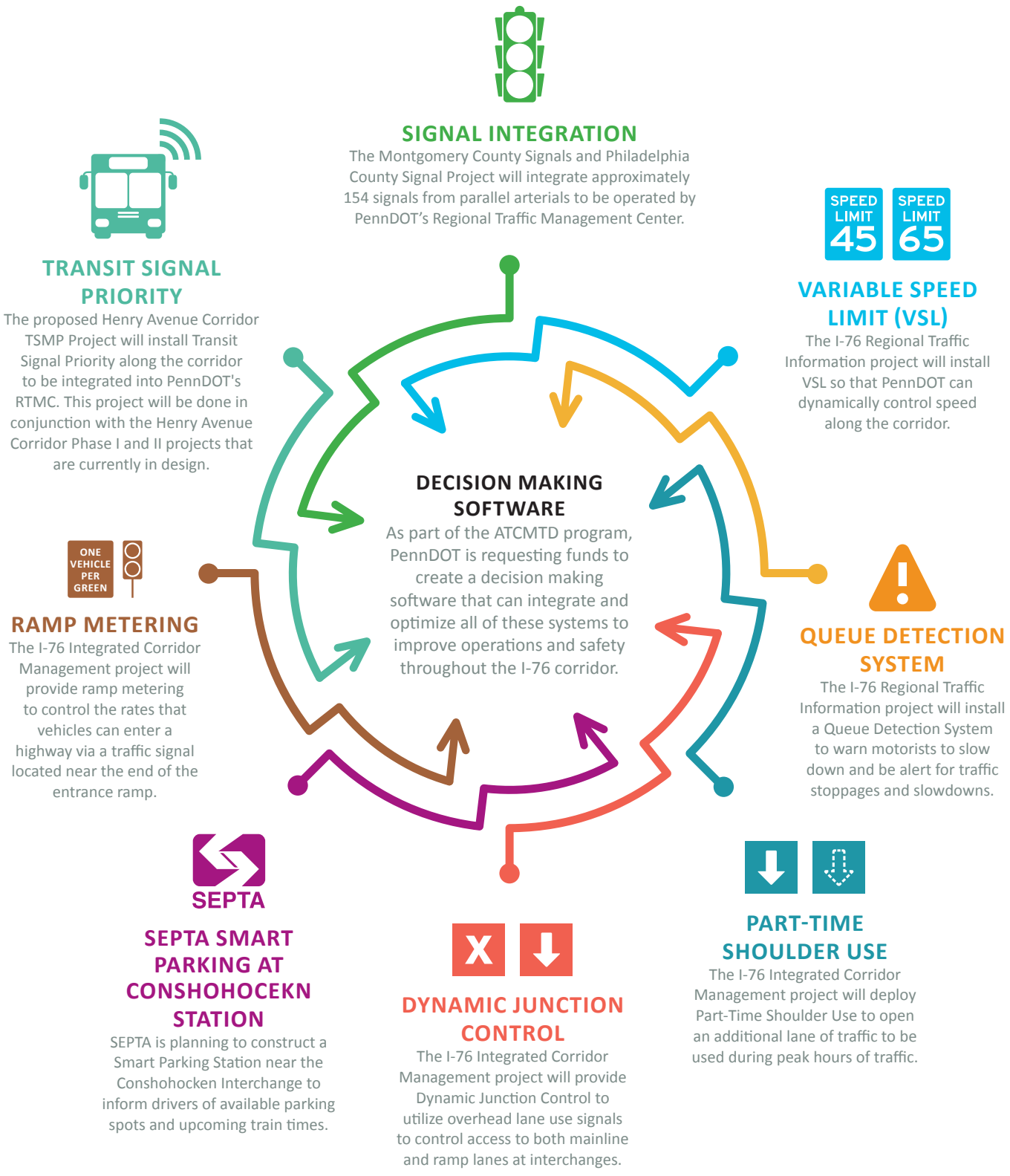
The ATCMTD Initiative is offered at a wonderful time for PennDOT District 6-0 and its partners to advance their ATM strategies and projects to the next level of performance. Described below are the two projects the team envisions to offer travelers and operating agencies both a way to capitalize upon existing and future technologies to better use the region's transportation infrastructure.

3.3.1 Integrated Corridor Management Decision Support System (DSS)

Any single ATM device and system can improve traffic operations or safety. Queue detection, for example, can warn drivers of upcoming congestion and to slow down, be alert, and consider alternate routes. However, the power of one device or system is amplified when a system of them can be used to more broadly assess the status of a traffic network. By having a system of several ATM strategies throughout a network PennDOT can assess the levels of congestion across multiple locations and travel options, and offer the traveling public this information. Travelers are now given actionable information to improve their trips, and operators can spot broader issues, assess them, and implement various congestion management strategies as necessary. It is the assessment and implementation steps that are the driving force behind creating and using Decision Support Software for the I-76 Corridor.

Operators

For the traffic operators working at PennDOT RTMC, the purpose of the decision support software is to manage a "system of systems". Along the proposed corridor, PennDOT will be managing up to eight different ATM system to manage congestion along the corridor network. The decision support software will analyze the traffic patterns along the corridor network to assist traffic operators to coordinate and select the appropriate response strategies using the ATM network. For example, when a major incident occurs on the



Figure—4 Decision Support Software

I-76 freeway, the DSS will evaluate response plans that will inform travelers of conditions and alternate travel recommendations on the existing area dynamic message signs and the 511PA web and mobile applications. The response plan may recommend use of a parallel route or to shift to transit, where there is spare capacity. Arterial route signal timing on the parallel routes would be changed to manage the flow of the diverted traffic, and transit operators may add additional cars to trains to handle the increase in passengers.

Traveling Public

Decision Support Software also provides the traveling public better information about traffic conditions along the network to make alternative choices with their trip. With the proposed ICM corridor being multi-modal, motorists can even chose to use a different mode of transportation to get to their ultimate destination.

By providing the traveling public better information via 511PA and DMS signs about traffic conditions ahead or the availability of parking spots at a regional rail station, motorists can choose their travel route and mode.

3.3.2 Henry Avenue TSMO Project

As part of its integrated corridor strategy for I-76, PennDOT is taking maintenance and operational responsibility of signals along several major parallel arterials. PennDOT will upgrade these signals and install ITS enhancements so that they can be actively manage from the RTMC in conjunction with the other ATM devices along mainline I-76.

One of the major arterials identified for signal integration in the *I-76 ITS Enhancement Conceptual Operations Report* was Henry Avenue. In preparation of taking these signals over, PennDOT programmed the Henry Avenue Congested Corridor Phase 1 and 2. The purpose of the project is to increase the safety along the corridor by upgrading the signals, ramps, guiderail and traffic signage. Since both projects are currently in the preliminary engineering phase, PennDOT, the City of Philadelphia and SEPTA decided to incorporate the following additional ITS enhancements to its application:

- CCTV
- Bluetooth Readers
- Travel Time System
- Arterial Dynamic Message Signs
- Transit Signal Priority

Figure—5 PennDOT District 6-0's RTMC

Figure—6 SEPTA's Control Center

Figure—7 City of Philadelphia Traffic Operation Center

Through the ATCMTD Initiative, these partner hope that TSP will advance the I-76 Multi-Modal Integrated Corridor Initiative by providing more reliable bus service along Henry Avenue and taking vehicular trips off of mainline I-76.

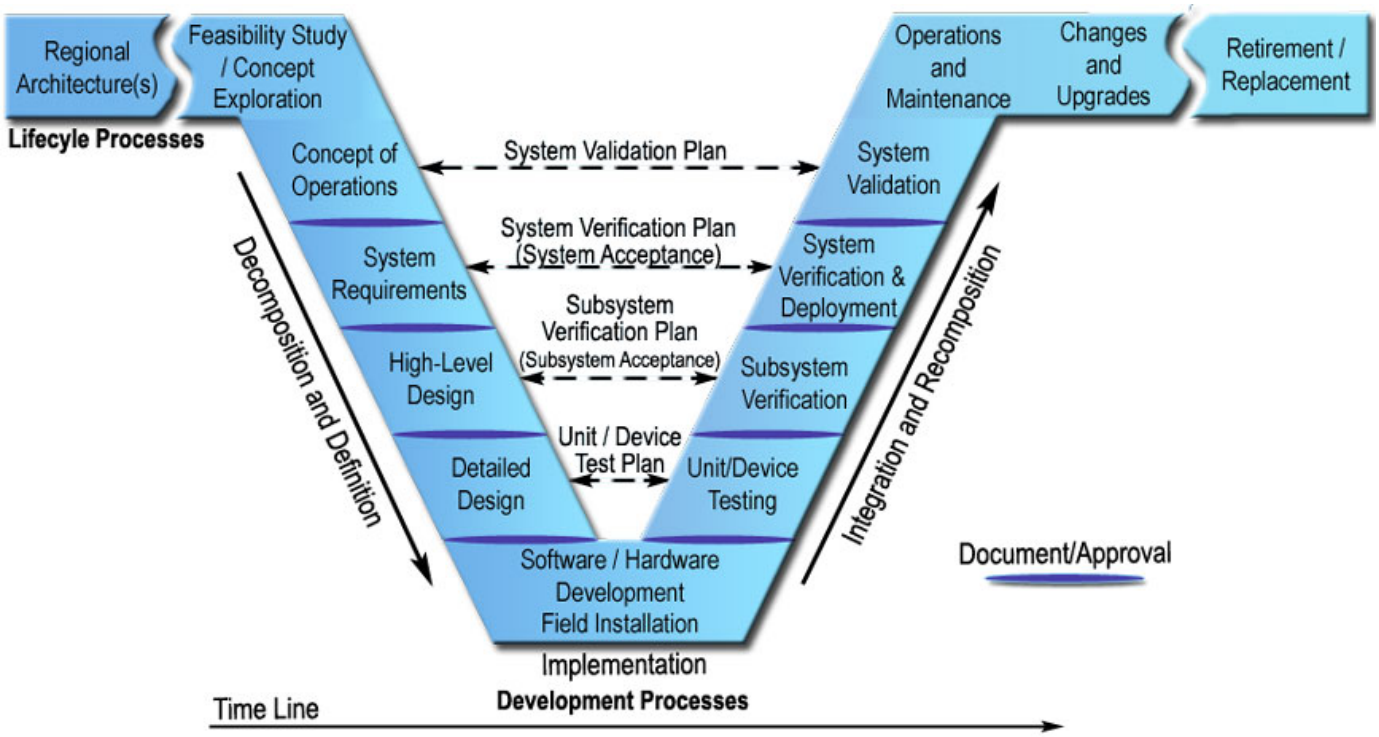
The strategy of taking trips off of I-76 is possible for the Henry Avenue Corridor. SEPTA Bus Routes 27, 32, and R provide connections to the Frankford Transportation Center, Center City Philadelphia and Plymouth Meeting (Montgomery County); Bus Routes 27 and R stop at the Wissahickon Transportation Center which is located at the I-76 Route 1 Interchange. Increasing transit mobility and travel time reliability along this corridor could truly provide another transportation alternative to and from Montgomery County and Center City Philadelphia and potentially take trips off of I-76.

3.4. Deployment Plan

The Deployment Plan for ICM Decision Support Software and the Henry Avenue TSMO will each follow the Systems Engineering Process. The ICM Decision Support Software is a new system that will be implemented as part of a new module in PennDOT's Statewide Advanced Traffic Management System (ATMS) software platform or will be separate software that is an overlay to the existing ATMS and all of the big data that it contains. The Henry Avenue TSMO system will be fully integrated into the existing ATMS with the Dynamic Message Signs (DMS), closed circuit television (CCTV) video, vehicle detection, travel time, variable speed limit and queue warning subsystems to allow seamless management of both planned and unplanned events. The CCTV system will help to monitor and validate traffic congestion and incidents on the roadway. The DMS will help to provide advance queue warning messages and an explanation for why the speed is reduced. The vehicle detection and travel time subsystems will collect data to be used in the Decision Support System to generate event response plans, and calculating travel times, and generating warning messages on DMS.

The Systems Engineering process begins with a Concept of Operations (ConOps) and continues through the V-Diagram (Figure 8) 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.

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.



Figure—8 Concept of Operations V-Diagram

3.4.1 Deployment Plan for ICM Decision Support Software

The I-76 ICM Decision Support Software System is proposed to build on the existing ITS and traffic and incident management systems to improve traffic operations and safety along the corridor.

The current vision of PennDOT and its stakeholders is the I-76 Multi-Modal ICM that envisions seamlessly optimizing traffic, transit, and multi-modal operations along the I-76 Schuylkill Expressway corridor. This includes TSMO improvements for both the mainline and parallel arterials, and ATMS software enhancements for ICM Decision Support System.

The ICM plan is to dynamically manage recurrent and non-recurrent congestion along the I-76 mainline and parallel arterials based on prevailing and predicted traffic conditions. The plan focuses on integrated systems with new technology and automation to optimize performance quickly for the I-76 corridor mainline and the parallel arterials to meet system-wide needs of congestion management, traveler information, and safety resulting in synergistic performance gains. Maximizing the efficiency of the corridor and trip reliability will include increased throughput and safety through ATM that influence travel behavior with respect to facility and mode choices and operations.

The ICM for I-76 will utilize a decision support system that reacts to prevailing and predicted traffic conditions and optimize the network to move people and goods from Point A to Point B as efficiently and safely as possible. PennDOT's current RTMC operations capabilities are generally in the Level 2 Managed category with a goal to progress into the Level 3 Integrated and ultimately Level 4 Optimized category. By progressing into the Integrated and Optimized areas, PennDOT can improve operations; meet its TSMO mission and the Vison Zero mission of Zero Deaths, Zero Delay.

PennDOT District 6 will be the lead agency in developing the software requirements, contract documents and oversight of the software vendor. The PennDOT will be responsible for hiring and managing a design consultant and software vendor to develop, test, install and integrate the ICM Decision Support System software. Table 2 and the paragraphs below provide brief of details the deployment process.

The Software Vendor shall develop a project management plan to identify the proposed activities for the planning, staff requirements and project organization, management of ongoing activities, progress reporting, and problem tracking and resolution, project schedule, and a software development plan to detail the proposed software development methodology, software configuration management, disaster recovery and software quality assurance.

The Functional Requirements will be reviewed and refined for use in the Business System Design Development which formally translates the baseline software functional requirements into a high-level system design using structured methodologies and includes:

- Requirements Matrix & Tracing (Baseline Requirements)
- Data Flow Diagrams (DFD)

INTEGRATED CORRIDOR MANAGEMENT DECISION SUPPORT SYSTEM (DSS) Procurement & Implementation	
PennDOT Design Consultant procurement	Using new solicitation or existing Consultant open end contract
Stakeholder Coordination Meetings	Engaged throughout entire project
Concept of Operations	Developed through Stakeholder involvement
Functional Requirements / RFP	Developed through Stakeholder involvement
Vendor Procurement	Anticipated RFP process
System Engineering Management Plan	Through RFP process and finalized at beginning of software design
DSS Final Functional Requirements	Refined through RFP process and finalized at beginning of software design
DSS Business System Design Document	Develops the business rules for system and integration plan
DSS Implementation - BETA version for Initial Testing	Provides initial view of the system user interface
DSS Implementation - Installation guide	
DSS Implementation - Troubleshooting Guide	
DSS Implementation - User & Administration Manuals	
System Validation & Acceptance Testing	RTMC Operator and design consultant oversight, Training Program
Deployment	Integrating the system into RTMC ATMS
Maintenance Period	O&M plan and software support

Table—2 Deployment for the Integrated Corridor Management Decision Support System

- Program Logic Modules – descriptions and definitions
- Preliminary Network Architecture
- Preliminary Estimates for network traffic, data storage and processing requirements
- Preliminary Database Designs and Sizing
- Preliminary Screens and Reports

The finalization of all design issues addressed in the preliminary Business System Design follows. Each module is decomposed to program and sub-routine level, data architecture design is finitely designed, sizing for all aspects of the system is completed. All reports and screens have been developed to the final design level, and database design is complete. All business rules have been identified and incorporated into the design. The requirements matrix & tracing has been updated to ensure the compliance of all requirements. The software installation guide, user and administration manuals and training manuals are prepared.

The remaining tasks and deliverables include the Software Test, Validation and Acceptance, Training, and Deployment and O&M.

3.4.2 Deployment Play for Henry Avenue TSMO Deployment

The Henry Avenue TSMO project is proposed to install ITS devices to improve traffic operations and safety along the corridor. The 20 signalized intersections include signal and controller upgrades, pedestrian accommodation improvements, minor roadway modifications and pavement marking improvements as part of the two existing Henry Avenue HSIP projects. The TSMO improvements for this corridor will build upon the HSIP improvements to add transit signal priority, CCTV cameras, arterial DMS, and a Blue Tooth Reader travel time system. All devices will be integrated into the regional fiber optic cable infrastructure and the City TOC ATMS and PennDOT RTMC ATMS. Henry Avenue is one of the critical parallel arterials to I-76 and the TSMO deployment will provide needed infrastructure to help manage the I-76 interstate and parallel arterial corridor.

The deployment plan for the Henry Avenue TSMO implementation will follow the Systems Engineering process. PennDOT District 6 will be the lead agency in developing the contract documents and oversight of the construction contractor. The City of Philadelphia will play a key role in design and construction to ensure their standards are met. The PennDOT will be responsible for hiring and managing a design consultant and construction contractor to develop, test, install and integrate the TSMO project. The following details the Henry Avenue deployment process.

PennDOT and the City of Philadelphia have successfully deployed similar arterial TSMO projects along Frankford Avenue, Ogontz Avenue, Allegheny Avenue, Woodland Avenue, Bustleton Avenue and 52nd Street.

3.5. Schedule

The attached schedule provides more details regarding the development of the Integrated Corridor Management Decision Support System and deployment of the Henry Avenue TSMO project.

It is anticipated that the Henry Avenue TSMO project can be incorporated into the existing Henry Avenue Congestion Corridor Phase 1 and 2 project and be completed by 2019.

The Integrated Corridor Management Decision Support System is anticipated to take longer however will be completed by 2021 and will help in managing the devices deployed for the I-76 corridor.

Henry Avenue TSMO Procurement & Implementation	
PennDOT Design Consultant procurement	Using new solicitation or existing Consultant open end contract
TSMO Design	Develop Concept of Operations, Systems Engineering Report, Construction Contract Documents
Construction Bidding	Low Bid process for prequalified ITS contractors
Construction – Physical Work & Field Integration	PennDOT oversight of contractor
Construction – ATMS integration	PennDOT /City oversight of integration into existing ATMS
Construction – Device & ATMS testing / Acceptance	PennDOT /City oversight
Construction – Operational & Maintenance Support Period	Contractor support of systems to ensure long term acceptance of devices and systems
PennDOT /City Operations & Maintenance	Following final project completion

Table—3 Deployment for Henry Avenue TSMO

I-76 Multi-Modal Intergrated Corridor Initiative
Implementation Schedule

	DURATION (months)	2017 Q4	2018 Q1	2018 Q2	2018 Q3	2018 Q4	2019 Q1	2019 Q2	2019 Q3	2019 Q4	2020 Q1	2020 Q2	2020 Q3	2020 Q4	2021 Q1	2021 Q2	2021 Q3
HENRY AVENUE TSMO DEVICE DEPLOYMENT	**36**																
ITS Device Design	12																
ITS Device Construction/Integration	12																
ITS Device O&M Support Period	12																
I-76 INTEGRATED CORRIDOR MANAGEMENT DECISION SUPPORT SYSTEM (DSS)	**48**																
Stakeholder Coordination Meetings	36																
Concept of Operations	6																
Functional Requirements / RFP	6																
Vendor Procurement	3																
DSS Final Functional Requirements	3																
DSS Business System Design Document	3																
DSS Implementation																	
BETA version for Initial Testing	9																
Installation Guide	3																
Troubleshooting Guide	3																
User & Administration Manuals	3																
System Validation & Acceptance Testing	3																
Deployment	3																
Maintenance Period	12																

Figure—9 Integrated Corridor Management Decision Support System and Henry Avenue TSMO Device Deployment

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4. Benefits

The benefits of ITS technologies to improve traffic operations by actively managing traffic have been displayed throughout the country. This section will discuss benefits that PennDOT anticipates to see with the deployment of the ATM devices and the additional benefits that will be seen with the deployment of a decision support system. (Figure 7)

4.1. ATM Benefits

The individual systems that are being deployed along I-76 provide are anticipate to provide the following safety and operational improvements to the corridor. Although these technologies have not yet been deployed along I-76, PennDOT's is anticipates the similar results to what other institutions have experienced.

4.1.1 Safety Benefits

According to FHWA's crash modification factors , the safety benefits are estimated for each of the following ATM strategies:

- Variable Speed Limits shows 8% crash reduction in rear-end crashes
- Queue detection shows 16% reduction in rear end crashes
- Ramp metering shows 35% reduction in rear-end/ side-swipe crashes due to merging

Queue detection systems have also proven to be beneficial in decreasing the number of rear-end crashes as a result of vehicles entering the back of a queue at a high rate of speed. Caltrans documented a 66% reduction in the number of queuing related crashes after deploying this system as well as Illinois DOT who documented a 14% reduction.

Shoulder use and junction control strategies do not currently show crash modification factors but recent FHWA publications indicate that crashes do not increase until ADT's reach a certain level which are much higher than along this corridor.

PennDOT anticipates meeting or exceeding these benefits when implementing VSLs, queue detection, and ramp metering along the corridor, thereby reducing the high number of crashes related to poor operation of the corridor discussed in Section 2.3 Issues.

4.1.2 Operational Benefits

Improving traffic operations to decrease travel delays and travel time; and increased reliability are some of the primary goals of the I-76 Multi-Modal Integrated Corridor Initiative.

The signal system improvement strategy for the parallel arterials will include controller upgrades, coordination, and connection to the PennDOT RTMC allowing for actively operating and updating the system and timing plans including incident timing plans to maximize corridor throughput. PennDOT anticipates that this will improve operations not only along the parallel arterials but also along mainline I-76 therefore reducing travel time and travel delay along the corridor.

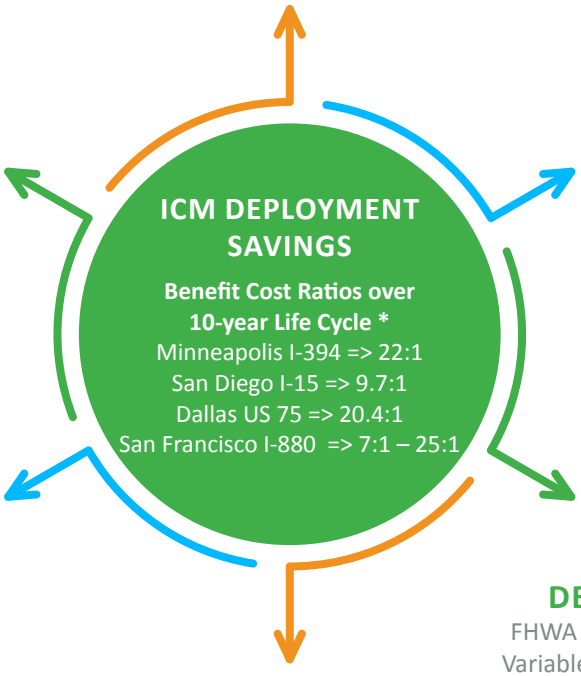
Studies have also shown reduced delay and improved travel times for variable speed limit systems. By monitoring traffic and weather patterns and dynamically changing, the PennDOT hopes to see an in increased throughput of 5 to 10%.

Based on District 6's own experience a 30% reduction in overall delay was seen from the ramp metering system it has implemented on I-476 and it is anticipated that ramp metering system will provide a reduction in overall delay.

Part-time shoulder use and junction control along I-76 could have significant impact on reduced delays and improved travel times. The Conceptual Operations study completed for the corridor anticipates that Part Time shoulder use will provide an additional 1,650 vehicles an hour in roadway capacity which can potentially improve operations during peak hour traffic.

4.1.3 Environmental Benefits

Although improving safety and traffic operations are the goal of the I-76 Multi-Modal Integrated Corridor Initiative, there are also environmental benefits when implementing these strategies. With improved traffic operations, there will be a reduction in travel time and idling which will therefore also reduce emissions and decrease fuel consumption: Minneapolis experienced a reduction of 175 tons of vehicular emissions and 17,600 gallons of fuel consumption per year; San Diego a 3,100 ton reduction in vehicular emissions and 323,000 gallons of fuel consumption; and Dallas a 9,400 ton reduction in vehicular emissions and a 981,000 gallon reduction in fuel consumption.



INCREASE: TRAVEL TIME RELIABILITY

Reliability improved by 4.4%, 10.6% and 3% in Minnesota, San Diego and Dallas

DECREASE: TRAVEL TIME

Annual savings of 132,000, 246,000 and 740,000 person-hours of travel in Minneapolis, San Diego and Dallas

DECREASE: FUEL CONSUMPTION

Reduction in consumption by 17,600, 323,000 and 981,000 gallons of fuel per year in Minneapolis, San Diego and Dallas

DECREASE: TRAVEL DELAY

Studies have shown reduced delay and improved travel times for Variable Speed Limit systems resulting in increased throughput of 5% to 10%. District 6 has a ramp metering system along I-476 which has shown 30% reduction in overall delay

DECREASE: CRASHES

FHWA crash modification factors for Variable Speed Limits shows 8% crash reduction in rear-end crashes, queue detection shows 16% reduction in rear end crashes, and ramp metering shows 35% reduction in rear-end/ side-swipe crashes due to merging

DECREASE: EMISSIONS

An annual reduction of 175, 3,100 and 9,400 tons of vehicular emissions in Minneapolis, San Diego and Dallas

* FHWA (2012). "Integrated Corridor Management Modeling Results Report: Dallas, Minneapolis, and San Diego." FHWA-JPO-12-037, February

Vassili Alexiadis, Brian Cronin, Steven Mortensen, and Dale Thompson (2009). "Integrated Approach: Inside Story on the ICM Test Corridor" Published by Traffic Technology International.

Figure—10 Benefits of the Project

In addition to the operational improvements providing environmental benefits, PennDOT and SEPTA also anticipate that the decision support software and TSP devices along Henry Avenue will improve SEPTA travel reliability, and therefore reducing the number of vehicles on I-76 and therefore improving emissions.

Additionally due to the multi-modal aspect of the project, it is anticipated that this will also have a positive impact on environmental justice communities. By deploying TSP devices along Henry Avenue, PennDOT and SEPTA anticipates more reliable travel times for bus routes along Henry Avenue therefore providing better access to from Philadelphia for populations that cannot afford personal vehicles.

4.2. ICM Benefits

Several areas of the country have been analyzing, modeling & simulating Integrated Corridor Management including Minnesota DOT, Texas DOT in Dallas, and CalTrans in San Diego and San Francisco. The following are a list of ICM projects that and the cost benefits they have received.

- Minnesota DOT estimated impacts of ICM deployment along the I-394 corridor to have a 22:1 benefit to cost ratio over a ten year life cycle and showed reductions in extreme travel times, improved travel time reliability, and reduced traveler delays, fuel consumption and emissions due to actively managing congestion.

- Dallas Texas, ICM Corridor showed a Decision Support system improved corridor travel times by 9% including freeway, arterial and transit network.

- San Diego's I-15 ICM Corridor initiative showed a 9.7:1 benefit to cost ratio over a ten year life cycle. San Francisco also evaluated ICM and combining multiple ICM strategies to help balance traffic flow and enhance corridor performance (freeways, arterials, transit) which provided a benefit to cost ratio of 7:1 to 25:1.

For the I-76 ICM and Decision Support System, the benefit from the individual systems are expected to be maximized and the overall benefit to cost ratio increased by actively managing the corridor network and providing travelers with travel time and congestion information for the freeway, arterials and transit.

5. Challenges

The challenges facing this project are quite minimal. The I-76 Multi-Modal Integrated Corridor Initiative has been well received by the public and public officials who welcome any strategy that will improve traffic operations along the important regional corridor. PennDOT has been actively engaging key stakeholders and public officials during the I-76 Conceptual Enhancement Concept Operational Report that was finalized in **.

Additionally the ATM strategy has very minimal environmental and right-of-way impacts as most of the improvements will occur on already disturbed land within PennDOT's existing right-of-way. The only challenge facing this initiative is having a decision support software in place to coordinate all of these devices.

5.1. Political Challenges

As part of its *I-76 ITS Enhancements Concept Operations Report*, PennDOT has already engaged the following key stakeholders to provide input on the proposed ATM Strategy for the I-76 Corridor:

- City of Philadelphia
- Delaware Valley Regional Planning Commission
- Federal Highway Administration (FHWA)
- Montgomery County Planning Commission (MCPC)
- Pennsylvania State Police (PSP)
- Southeastern Transportation Authority (SEPTA)

The following local municipalities in Montgomery County were also engaged during the process to understand their operational needs and to discuss the I-76 Parallel Arterial Signal System project:

- Upper Merion
- Lower Merion
- Plymouth Township
- Whitemarsh Township
- Bridgeport Borough
- Conshohocken Borough
- Norristown
- West Conshohocken Borough
- Radnor Township

This outreach will continue as PennDOT moves forward with all components of the I-76 Multi-Modal Integrated Corridor Initiative.

Figure—11 SEPTA Bus Route 32 in Center City

5.2. Environmental Challenges

There will be no environmental impacts for the I-76 Integrated Corridor Management Decision Support Software project as the project does not involve any construction activities. The Henry Avenue TSMO Device Deployment Project does involve construction activities however it is anticipated that the impacts will be minimal since all work will be completed within the existing right-of-way.

5.2.1 Cultural Resources

There are no anticipated archaeological impacts to the project as all the signal work and ATM device upgrades will take place on already disturbed ground.

However, Henry Avenue runs adjacent to Fairmount Park which is one of the City of Philadelphia's oldest parks and listed on the National Register. It is anticipated that this project will not have any adverse effect on the resource due to the scope of work of the project, which is limited to adding ITS and ATM devices on the signals, It is anticipated that the project can be exempted using PennDOT and FHWA's programmatic agreements.

5.2.2 Right-of-Way Impacts

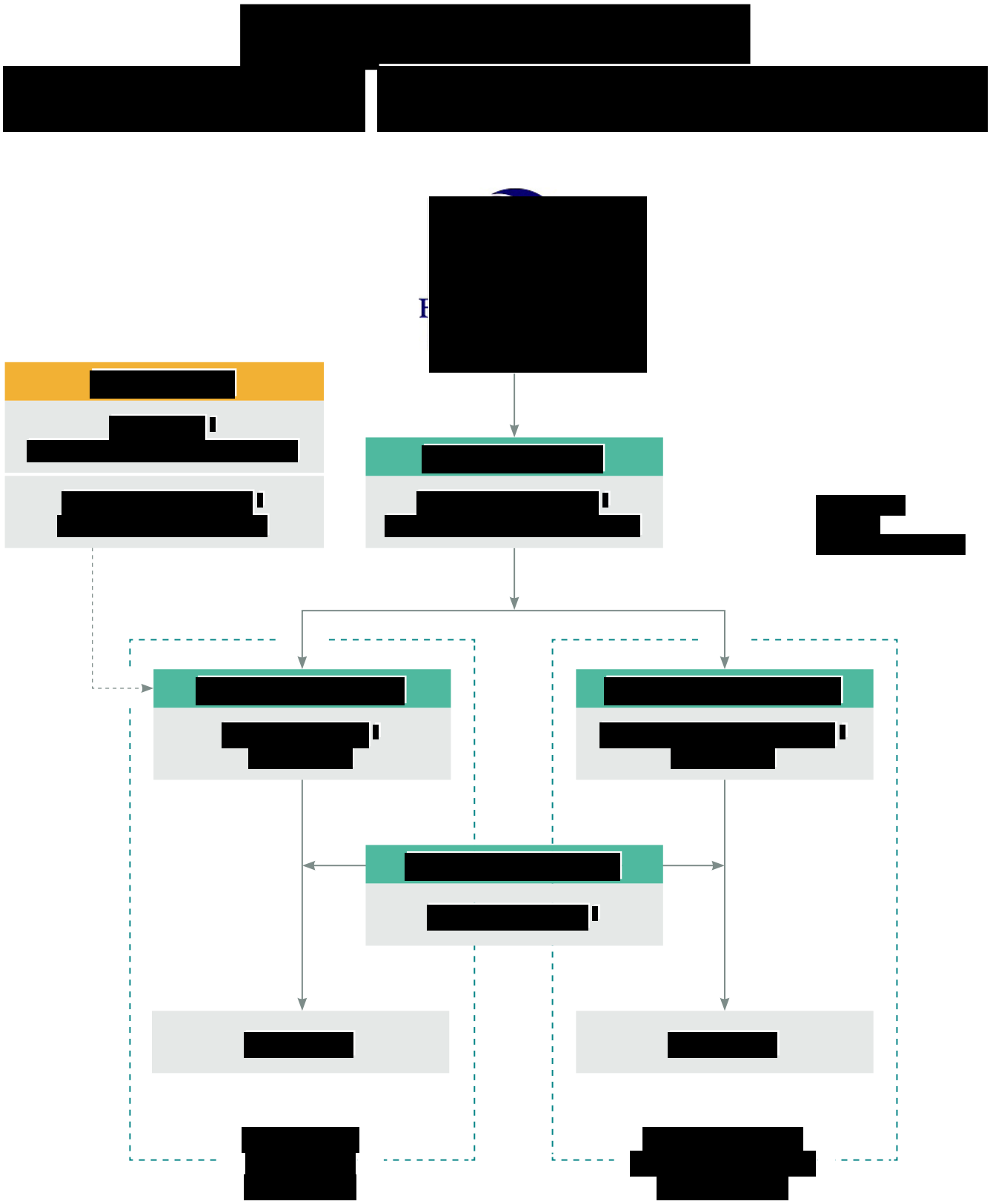
There are no right-of-way impacts anticipated as part of this project since all signal upgrades and ATM device deployment will occur within existing PennDOT right-of-way.

The risk and challenges associated with this project is minimal and it is anticipated that once federal ATCMTD funds are received that the project can proceed relatively quickly and meet the deadlines required of the program.

The ICM Decision Support Software is a new system that will be implemented as part of a new module in PennDOT's Statewide Advanced Traffic Management System (ATMS) software platform or will be separate software that is an overlay to the existing ATMS and all of the big data that it contains. PennDOT has recent experience over the past five years with software design and development through the statewide ATMS software. Through the ATMS software project, PennDOT has a strong understanding of the challenges, process and risks involved in this type of project.

6. Partnering Plan

[redacted]



Figure—12 Organization Chart for the I-76 Multi-Modal Integration Corridor Initiative

7. Conclusion

PennDOT District 6-0 thanks FHWA for considering our proposal.

The I-76 Multi-Modal Integrated Corridor Initiative addresses the problem of congestion for a highway that cannot be widened. The proposed decision support software and multi-modal technologies that will be deployed as part of this project will optimize the existing and proposed systems that the region is implementing to provide even more reliable travel times for motorists and public transit by coordinating all the traffic management devices to work together.

If successful along this corridor, PennDOT envisions implementing this software and these strategies along other Highway Systems with other partners. Such improvements would benefit I-95 which has many freight, rail, toll bridge authorities and public transit partners that would benefit from a decision support software that would optimize the ATM devices along the corridor. It would also greatly benefit the ATM strategies already deployed along the I-476 corridor which like I-76 cannot be widened due to land use and environmental constraints.

This program will help PennDOT and the region to continue to support the growing Philadelphia metropolitan region and advance traffic technologies into the future.

Appendix A

List of Resumes