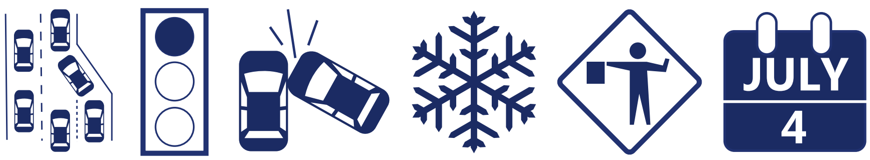
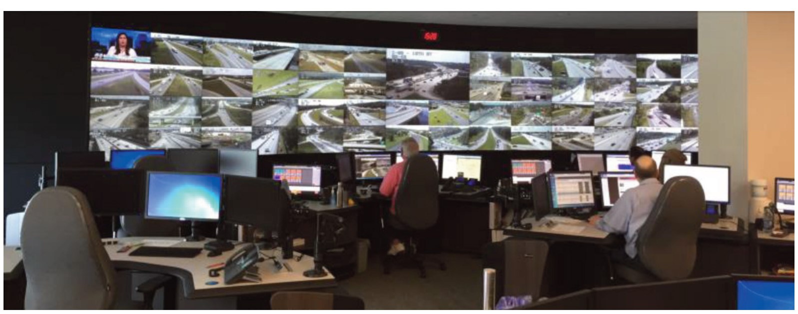
TRANSPORTATION SYSTEMS MANAGEMENT AND OPERATIONS (TSMO)

Guidebook

PART I: PLANNING



TSMO



pennsylvania
DEPARTMENT OF TRANSPORTATION

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Abbreviations and Acronyms

Many abbreviations and acronyms are used in TSMO, with several of the common ones listed below:

Abbreviation/Acronym	Term
AADT	Average Annual Daily Traffic
BPPR	Baseline Performance Period Report
CCTV	Closed Circuit Television Camera
CFR	Code of Federal Regulations
DDP	Device Deployment Plan
DMS	Dynamic Message Sign
FAST	Act Fixing America's Surface Transportation Act
FPPPR	Full Performance Period Progress Report
FHWA	Federal Highway Administration
FSP	Freeway Service Patrol
FTA	Federal Transit Authority
HAR	Highway Advisory Radio
ISTEA	Intermodal Surface Transportation Efficiency Act
ITS	Intelligent Transportation System
LRTP	Long-Range Transportation Plan
MAP-21	Moving Ahead for Progress in the 21st Century
MPPPR	Mid Performance Period Progress Report
MPO	Metropolitan Planning Organization
MTP	Metropolitan Transportation Plan
NEPA	National Environmental Policy Act
NHS	National Highway System
O&M	Operations and Maintenance
PA	Commonwealth of Pennsylvania
PennDOT	Pennsylvania Department of Transportation
PDA	Probe Data Analytics Suite (part of RITIS)
PMC	Program Management Committee
RCRS	Roadway Condition Reporting System
RITIS	Regional Integrated Transportation Information System
ROP	Regional Operations Plan
RPO	Rural Planning Organization
RTMC	Regional Traffic Management Center
RWIS	Roadway Weather Information System
SAFETEA-LU	Safe Accountable Flexible Efficient Transportation Equity Act: A Legacy for Users
STIP	Statewide Transportation Improvement Program
TEA 21	Transportation Equity Act for the 21st Century
TIM	Traffic Incident Management
TIP	Transportation Improvement Plan
TMC	Traffic Management Center
TSMO	Transportation Systems Management & Operations
TSS	Traffic Signal System
TYP	Twelve (12) Year Program
UPWP	Unified Planning Work Program
VD	Vehicle Detection

Chapter 1. Introduction

Purpose of the Guidebook

The purpose of this document is to describe how to implement the Pennsylvania Department of Transportation's (PennDOT) statewide approach to Transportation Systems Management & Operations (TSMO). TSMO is a set of integrated strategies used to optimize the operational performance of existing infrastructure. In simplest terms, TSMO is a way to increase reliability and mobility of our roadways by using a wide-range of strategies rather than adding capacity to manage congestion.

The first step in implementing TSMO is to plan investments, including both capital (long-term) infrastructure upgrades and ongoing (short-term) maintenance and operations functions. While capital projects are a key part of TSMO, transportation systems will not achieve the desired outcomes without simultaneous investments in maintenance, operations, and management. This document describes how TSMO fits within the overall transportation planning process in Pennsylvania and provides guidance for the preparation of two key planning documents for TSMO implementation: Regional Operations Plans (ROPs) and Business Area Plans.

Part I: Planning of this Guidebook is intended for professionals responsible for transportation planning and operations within Pennsylvania who are working for or on behalf of PennDOT, Metropolitan Planning Organizations (MPOs), Rural Planning Organizations (RPOs), and local municipalities. These various stakeholders should use this Guidebook throughout the development and implementation of their transportation operations plans and programs. Using this Guidebook will also assist stakeholders and organizations in advancing to higher levels of the Capability Maturity Model (CMM), which "identifies key dimensions of process and institutional capability that directly relate to improving program effectiveness," according to the Federal Highway Administration's (FHWA's) Office of Operations. FHWA indicates the CMM process "was created to help agencies identify strengths and weaknesses of their existing traffic operations programs, current capabilities associated with various business processes, and actions that could be taken to help move the program to a more advanced level." The CMM has a four-level system identify levels of agency capability: performed, managed, integrated, or optimized.

TSMO Business Area Plans are the primary source of documenting PennDOT's various TSMO functions, and are described in more detail in Chapter 2.

Regional Operations Plans (ROPs) play an important role in regional Long-Range Transportation Plan (LRTP) and Transportation Improvement Program (TIP) processes by helping to secure future capital funding for projects incorporating TSMO solutions. Keeping ROPs up-to-date is critical to ensure that they maintain the proper role in implementing TSMO-related projects in a systematic manner, rather than through ad-hoc additions to other capital projects. ROPs are described in more detail in Chapter 3.

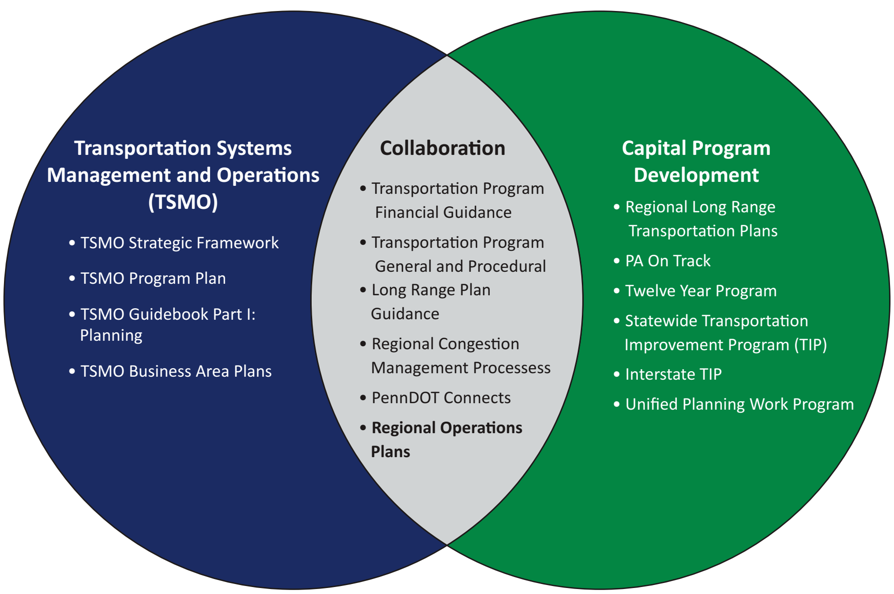
This document seeks to clarify and strengthen the connection between various planning processes, such as the Congestion Management Process (CMP), the LRTP, the ROP, the Regional ITS Architecture, and the TIP. Both as standalone projects and as portions of other projects, TSMO solutions will benefit from a strong connection to the TIP, in order to be prioritized during project planning.

Additionally, the TSMO Program Plan identifies the need for the provision of proper documentation, tools, data, and systems necessary to evaluate and execute operations strategies. This document provides guidance on how to use available data sources to evaluate traffic operations performance to fulfill this need.

TSMO Planning Framework

Several documents and plans relating to the planning and programming of TSMO comprise the TSMO Planning Framework, as described below. Figure 1 illustrates the relationship between PennDOT's TSMO Program (shown in blue) and PennDOT's Capital Program Development (shown in green). The gray area represents documents, plans, and processes which require collaboration between the two programs. Most of these represent areas in which TSMO topics will be incorporated into existing documents used for the Capital Program Development. The final bullet, Regional Operations Plans, is a plan developed under the TSMO Program which feeds projects into the Capital Program.

FIGURE 1: TSMO RELATIONSHIP WITH PLANNING PROCESS



TSMO Strategic Framework

The TSMO Strategic Framework provides an overview of the importance of TSMO and the need for creating a program in Pennsylvania. The Strategic Framework presents the overarching vision, mission, and goals that will drive the development of the TSMO Program as well as challenges that must be overcome. The Strategic Framework is based on the current operation environment of PennDOT and the current project planning and programming processes within Pennsylvania.

TSMO Program Plan

The TSMO Program Plan builds off the TSMO Strategic Framework and presents the Capability Maturity Model (CMM)-based approach to reach the vision, mission, and goals. The CMM approach is based on needs, strategies, and actions during stakeholder outreach and are specific to the development and advancement of the TSMO program in Pennsylvania. The TSMO Program Plan also includes a schedule and implementation plan to advance each CMM dimension by delegating responsibilities to the PennDOT Business Areas. The plan identifies what dimension it will advance, its dependencies with other strategies, and a listing of additional resources needed to accomplish the strategy/action.

Earlier planning for operations is identified as Need A in the TSMO Program Plan. Transportation operations is frequently an afterthought in the project development process. Successful operation of a transportation network should start during the planning stages and continue through design, construction, maintenance, and operations. Because of this disconnect, many of the documents and processes used by the planning partners do not include an evaluation of potential operations strategies or have not been updated within a reasonable timeframe to be included in the project development process cycle.

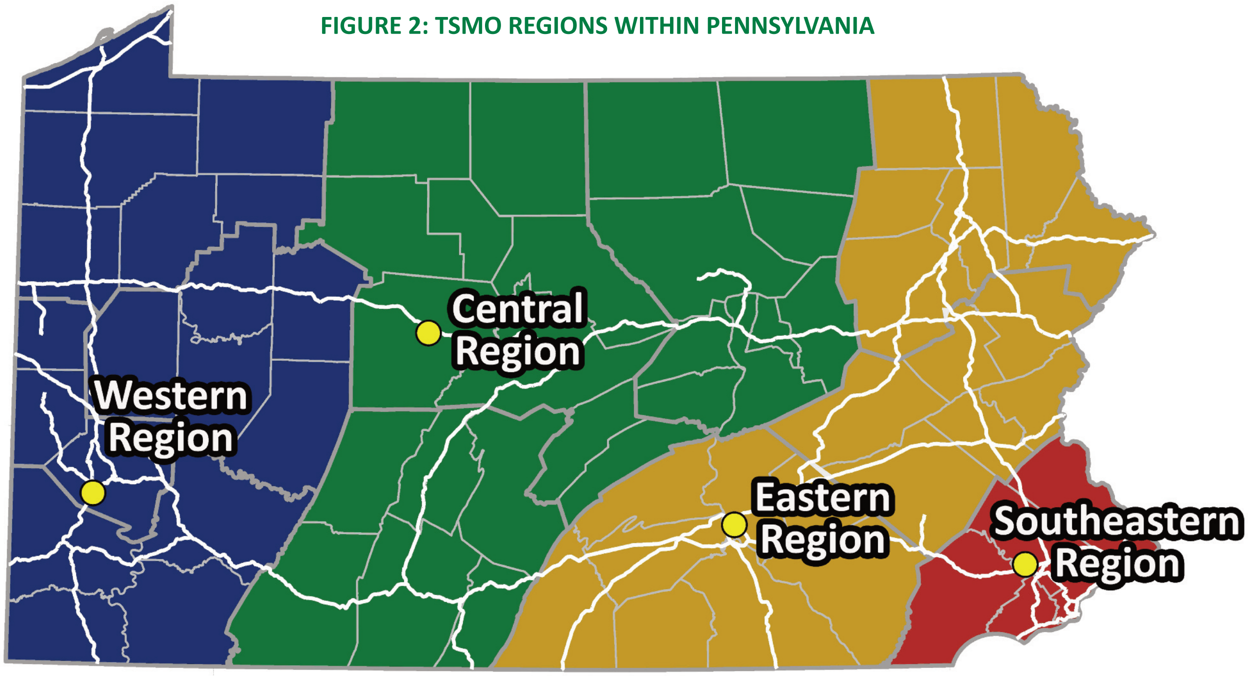
TSMO Business Area Plans

TSMO Business Area Plans will build off the TSMO Strategic Framework and TSMO Program Plan by assigning responsibility for each action of the Program Plan, identifying the CMM dimensions it will advance, scheduling dependent actions, and identifying additional resources which are necessary for implementation. PennDOT will develop these plans as they primarily dictate internal PennDOT operation. The TSMO Business Area Plans will include a CMM for the applicable business area and metrics for their operations. Additional information relating to the content and preparation of Business Area Operations Plans is contained in Chapter 2.

Regional Operations Plans (ROPs)

Regional Operations Plan (ROP) development follows a typical planning process, such as the one used for the development of a regional LRTP. Through the ROP process, the existing ITS and Operations infrastructure, needs, visions and goals are identified in order to ultimately prioritize future operationsfocused projects and performance measures that are in harmony with regional, state and federal policies.
ROPs are intended to be included, by reference, within the LRTP. The TSMO regions in Pennsylvania are shown in Figure 2. Previously, nine ROPs were created across Pennsylvania, but the number of regions has been reduced to four to better align the planning of operations with PennDOT's four Regional Traffic Management Centers (RTMCs). Additional information relating to the content and preparation of ROPs is contained in Chapter 3.

FIGURE 2: TSMO REGIONS WITHIN PENNSYLVANIA



Statewide Policy and Direction Setting

The TSMO Planning Framework documents provide operational guidance for several strategic planning initiatives within PennDOT. While these documents were developed prior to PennDOT's initiation of TSMO efforts, these plans support the operational strategies for managing the transportation system as described in more detail below.

PennDOT 20/20 Strategic Direction

PennDOT 20/20 is the overarching document that drives PennDOT forward by solving current and future challenges and by defining PennDOT's Vision, Mission, and Values. One of the six Strategic Themes in PennDOT 20/20 is Effective Partnerships, which recognizes the needs of local and planning partner stakeholders within delivering the transportation program.

PennDOT Investment Plan

TSMO is addressed within PennDOT's Investment Plan, which recommends that regional traffic operations/ITS projects and strategies should be consistent with the guidance provided within this Guidebook. The Investment Plan also notes that projects should be included in a Regional Operations Plan to ensure consideration for funding as part of the overall planning process.

PA On Track: Pennsylvania's Long-Range Transportation Plan

PA On Track is Pennsylvania's long-range transportation plan. It is a strategic, multimodal, performancebased plan that establishes PennDOT's vision for transportation in Pennsylvania. PA On Track also includes a Comprehensive Freight Movement Plan. Both plans were developed in accordance with the guidance provided by MAP-21 federal legislation. PA On Track is organized around four goal areas – system preservation, safety, personal and freight mobility, and stewardship – that support the achievement of Pennsylvania's transportation vision and guide PennDOT in addressing the state's transportation priorities. TSMO is addressed extensively within the plan's objectives and strategies for personal and freight mobility.

Typical Transportation Program Development Documents

Planning partners create and update several documents that define how and where transportation funds are invested. TSMO Solutions can be integrated into each of these documents to plan and fund projects, and elements of projects, that support mobility goals.

Long-Range Transportation Plan (LRTP)

The purpose of the long-range transportation planning process is to identify the overall vision and goals for a regional transportation system and a means for meeting the identified goals. The LRTP addresses current and future land use, economic development, environmental concerns (natural, human, and cultural), traffic demand, revenue projections, public safety, health, and social needs, as all of these issues affect the existing and future transportation system. Future LRTPs will be required to include performance measures in accordance with federal regulations. The LRTP is required to include a 20-year planning horizon. It includes a public participation component and often includes alternatives analyses. The LRTP drives future investment decisions for transportation. The strategies or projects identified in the LRTP are to be considered as future TIPs are developed.

Twelve Year Program (TYP)

Every two years, PennDOT is required to prepare and submit a program of transportation improvements to the State Transportation Commission (STC), which it recommends be undertaken during the next twelve years. The resulting TYP is the fiscally constrained, official transportation program for the state. The TYP is organized into three four-year program periods and addresses all transportation modes. The first four-year program coincides with the State Transportation Improvement Program (STIP) and TIPs. The planning partners collaborate with PennDOT in the program's development.

Transportation Improvement Program (TIP)

The TIP is a financially constrained regional list of prioritized, multimodal transportation projects, including anticipated costs and schedules, as required by federal law (ISTEA, TEA-21, SAFETEA LU, MAP-21, and FAST). The TIP is the delivery mechanism for advancing the regional transportation investments identified in the LRTPs, including all projects that intend to use federal funds and all non-federally funded projects of regional significance. The TIP schedules all transportation investments and project phases to be advanced over the upcoming four years. The TIP is updated every two years, consistent with the TYP, and reflects the first four years of the TYP. The TIP can be amended or modified over time and can include miscellaneous federal line items for discretionary projects. More information on the TYP and the TYP process is available at www.talkpatransportation.com.

Congestion Management Process (CMP)

A CMP is federally required in any metropolitan area designated as a Transportation Management Area (TMA), which are typically urbanized areas with a population exceeding 200,000, and is prepared by the MPO for the area. The CMP is a systematic process for managing congestion and brings congestion management strategies to the funding and implementation stages of the project development process to improve the performance and reliability of a multimodal transportation system.

In TMAs designated as ozone or carbon monoxide non-attainment areas, the CMP becomes even more important since federal law prohibits projects that result in a significant increase in carrying capacity for single occupant vehicles from being programmed in these areas unless the project is addressed in the region's CMP.

While CMPs may seem similar to ROPs, there are some distinct differences between the two plans. Both plans identify TSMO solutions to address mobility issues, but the geographic scope is different, as ROPs generally cover a larger area than the TMA where a CMP is required. Planning Partners preparing CMPs are encouraged to utilize strategies from the ROP for their region as part of the CMP. Planning Partners may wish to align their CMP updates with the ROP update timeline in order to allow both documents to feed projects into the LRTP.

Unified Planning Work Program (UPWP)

The UPWP is a biennial document developed by MPOs to identify the planning priorities and activities for a metropolitan planning area. The UPWP specifically details the planning work to be completed, the entities that will perform the work, the final deliverables, and the associated schedules, costs, and funding sources. These Programs are required for any work programs that utilize FHWA and Federal Transit Administration (FTA) planning funds. Therefore, any TSMO planning needs should also be included in the UPWP.

Project Development Process

PennDOT's Transportation Program Development and Project Delivery Process is defined in Publication 10, Design Manual Part 1 (DM-1). After the identification of potential transportation problems by PennDOT and its planning partners, these stakeholders develop Project Needs, identify potential alternatives, ensure environmental responsibility, and create a fundable TIP containing proposals and potential projects that will sustain and enhance the Commonwealth's transportation network. Capital investments to implement TSMO solutions will be implemented through projects using this process and funded through the TIP. These projects should be identified as part for the ROP for the applicable region.

DM-1 describes ten Core Principles upon which PennDOT's Transportation Program is developed. TSMO solutions can be successfully deployed as independent projects or as components of other projects which build consistency with the Core Principles. Whether deployed as independent projects or as components of other projects, examples of how TSMO Solutions can address specific Core Principles include:

- *Core Principle #2:* Choose Projects with High Value to Price Ratios. TSMO Solutions typically have higher value to price ratios than capacity-adding projects and can provide metrics that help determine whether the degree of improvements are justifiable based on the total required investment.
- *Core Principle #3:* Enhance the Local Network. TSMO Solutions encourage the improvement of operations using the existing alignment and often within the current roadway footprint, which inherently reduces the complexity of environmental impacts and utilizes the existing right-of-way.
- *Core Principle #6:* Accommodate all modes. By focusing on the safe and efficient movement of people and goods, TSMO Solutions seek to maximize use of all modes of transportation by maximizing the efficient use of capacity within each mode.
- *Core Principle #7:* Leverage and Preserve existing investments. TSMO Solutions focus on leveraging the maximum capacity available through existing infrastructure rather than building new capacity.

TSMO Solutions may be implemented through independent projects or as a part of other types of projects. Stakeholders are encouraged to consider the applicability of TSMO Solutions for every project as part of the design process outlined in DM-1.

Managing Congestion

Congestion occurs when the traffic demand exceeds the available capacity, and can occur if there is a surge in demand, a reduction in physical capacity, or a combination of both. Understanding congestion is critical to effective implementation of TSMO strategies. This Guidebook establishes a framework for understanding the various sources of congestion, the ways to address congestion by targeting these sources, and performance measures for monitoring trends in congestion. This process was originally outlined in *Traffic Congestion and Reliability: Linking Solutions to Problems*, prepared for the Federal Highway Administration (FHWA) by Cambridge Systematics, Inc. with the Texas Transportation Institute in 2004. PennDOT has adapted this process into three main congestion management activities: 1) identify congestion, 2) classify congestion, and 3) mitigate congestion, as shown in Figure 3:

FIGURE 3: PENNSYLVANIA CONGESTION MANAGEMENT FRAMEWORK

The first activity, **identifying congestion**, provides baseline measures to quantify the extent and severity of congestion. The second activity, **classifying congestion**, identifies the root cause for each instance of congestion. The third activity, **mitigating congestion**, selects and applies targeted strategies based on the predominant cause of the congestion. After the mitigation efforts are applied, the extent and severity of any remaining congestion can then be identified to monitor any trends, thus continuing the repeating cycle. Chapters 4-6 of Part I: Planning of this Guidebook describe this process in more detail.

Chapter 2. TSMO Business Area Plans

[Reserved – this chapter will be completed at a later date]

Chapter 3. Regional Operations Plans

Introduction

This chapter provides guidance and a template for the process of developing and documenting a Regional Operations Plan (ROP). Each ROP complements the TSMO Program Plan by identifying the regional approach to traffic operations and sets the stage for regional implementation of TSMO strategies.

This guidance will help to ensure the establishment of well-defined, consistent ROPs across Pennsylvania, enabling Pennsylvania to:

- Meet federal requirements related to ITS planning (23 CFR 940)
- Incorporate statewide TSMO goals for operations planning at the regional level
- Utilize objectives-driven, performance-based planning processes for operations and congestion management planning
- Integrate/mainstream ITS and operations planning into the overall transportation planning process, as per FHWA guidance
- Prioritize and fund TSMO capital projects as part of the Transportation Improvement Program (TIP)
- Manage funds for the TSMO operations and maintenance (O&M) in future years

A ROP will be developed for each of the four Operations Regions, identified previously in Figure 2, which the RTMC will manage with support from the various planning partners in the region.

ROPs should have an update cycle of every four or five years. Similar to the LRTP, the ROP should, at a minimum, identify which projects could be undertaken within the first four years, aligning these projects for potential inclusion in the TIP.

ROP Development Process

ROP development follows a typical planning process, such as the one used for the development of a regional LRTP, as shown in Figure 4. Through the ROP process, the existing ITS and Operations infrastructure, needs, visions, and goals are identified to develop future projects and performance measures that are in concert with regional, State, and Federal policies. The TSMO Program Plan provides guidance on statewide goals, objectives, and performance measures. Statewide and regional performance measures provided by PennDOT and various analytical tools can be used to assist regional planners in determining and prioritizing transportation and operational needs.

FIGURE 4: ROP PLANNING PROCESS

Regional Goals & Objectives

The process stresses the development of operations objectives which tie to regional policy goals and strategies, which are typically set forth in the LRTP. Traditionally, the implementation of projects was considered a measure of success, without any additional review of how well those projects addressed the actual needs of the system once they were completed. To address this disconnect, the identification of TSMO projects should be based on transportation needs and be both objectives-driven and performancebased (as prescribed by FHWA). TSMO projects will be selected based on benefits to mobility, safety, and operational needs, and will also be comparable and competitive with other projects in the TIP process. An example of a traditional approach compared with an objectives-driven and performance-based approach is shown in Table 1.

TABLE 1: EXAMPLE OBJECTIVES-DRIVEN AND PERFORMANCE-BASED APPROACH

	Traditional Approach	Objectives-Driven and Performance-Based Approach
Transportation System Observation	Congestion along a corridor	Congestion along a corridor, specifically identified as incident-based.
Transportation System Need	Deployment of additional CCTV cameras	Incident Management (could include CCTV coverage) along a corridor, based on the number of crashes/incidents or non-recurring congestion
Performance Measure	Number of CCTV cameras deployed	Reduction in the number of crashes and/or delays due to incidents along the corridor

One method which can be used to establish an objectives-driven, performance-based framework for TSMO Planning is the GOST (Goals, Objectives, Strategies, Tactics) Model, which focuses on both short term and long-term system performance and includes the following elements:

- **Goals** are broad outcomes and define "what" is trying to be accomplished
- **Objectives** are measurable, specific, and are subsets of the goals
- **Strategies** detail "how" the defined objectives will be achieved
- **Tactics** are the actions that are used to achieve the defined objectives and associated strategies

The regional goals, objectives, strategies, and tactics should be consistent with the statewide goals and objectives established in the TSMO Program Plan and support advancing to higher levels of the CMM.

Strategy Development

A systematic process is needed to develop and select TSMO Strategies that meet the defined objectives. Performance measures, that are tied to the goals and objectives, should be used as part of this process. These measures provide a basis for tracking how well the strategies are fulfilling the mission, rather than the traditional method of focusing on the implementation of projects as a measure of success.
Effective performance measurement is central to TSMO, since the way that performance is defined and measured will significantly affect the types of projects and strategies that are advanced. Performancebased results will inform agencies as to whether the types of projects and strategies that are being implemented are helping to achieve their strategic performance goals. To summarize, performance measures play the following roles in TSMO:

- Clarifying the definition of goals
- Monitoring or tracking performance over time
- Tracking goals and objectives
- Providing a reference for target setting
- Providing a basis for supporting policy and investment decisions (alternatives comparison)
- Assessing the effectiveness of projects and strategies

PennDOT has three external TSMO Program goals:

1) **Mitigate recurring congestion**
2) **Maintain mobility during planned incidents**
3) **Minimize the traffic impact of unplanned events**

There are various congestion causation factors within each of these goals, as shown in Table 2. By defining the goals this way, each congestion causation factor is accounted for within the GOST framework. The framework lends itself to identifying responsible stakeholders and their relationship to improving congestion within the state. The three goals are, in turn, supported by nine different outcome-based objectives, which are achieved through the identification of strategies and tactics. The goals and objectives are shown in Table 2.

TABLE 2: CONGESTION CAUSATION AND OUTCOME-BASED OBJECTIVES RELATIVE TO TSMO GOALS

<table>
<tr><th>TSMO Goals</th><th>Causes of Congestion</th><th>Objectives</th></tr>
<tr><td rowspan="3">Mitigate Recurring Congestion</td><td rowspan="2">Bottlenecks</td><td>Reduce vehicular demand during peak hours</td></tr>
<tr><td>Improve capacity during peak hours</td></tr>
<tr><td>Poor Signal Timing</td><td>Optimize the timing of traffic signals</td></tr>
<tr><td rowspan="2">Maintain Mobility During Planned Events</td><td>Work Zones</td><td>Optimize work zone mobility</td></tr>
<tr><td>Special Events/Other</td><td>Improve mobility during special events</td></tr>
<tr><td rowspan="4">Minimize Traffic Impacts During Unplanned Events</td><td rowspan="2">Traffic Incidents</td><td>Minimize the incident influence time</td></tr>
<tr><td>Improve mobility on identified detour routes</td></tr>
<tr><td rowspan="2">Inclement Weather</td><td>Manage mobility during weather events</td></tr>
<tr><td>Minimize the weather event clearance time</td></tr>
</table>

The performance measures should be directly related to the defined goals and objectives. Chapter 4 describes, in detail, eight basic performance measures which can be utilized to identify and quantify congestion. Stakeholders may also develop additional performance measures to support goals and objectives in the ROP. Once the goals, objectives, and performance measures have been identified, the GOST framework can be completed by developing the strategies and tactics, as illustrated in the example shown in Table 3.

TABLE 3: SAMPLE GOST FRAMEWORK
Goal: Minimize the Traffic Impacts During Unplanned Events

Objective: Minimize the incident influence time	**Performance Measures:** Buffer Time Index (ratio of worst case travel time to average travel time)
Strategy: Provide incident information to travelers	**Tactic:** Use Dynamic Message Signs to provide advance notice of incidents and alternate route information

Collect Data/Monitor System Performance

After performance measures are defined, data should be collected and analyzed to assess how the roadway system is operating. Data collection in Pennsylvania is supplemented by PennDOT via the PDA Suite, which is available to planning partners.[1] The congestion performance measures described in Chapter 4 can be utilized to evaluate congestion issues and develop ranking and prioritization for areas in need of operational enhancements. Probe speed data, purchased by PennDOT, can be utilized to generate the eight congestion identification performance measures described in Chapter 4 using the PDA Suite and

[1] The Probe Data Analytics Suite (PDA) is a tool that allows agencies to support operations, undertake planning activities, and develop performance measurement reports. The suite consists of a collection of data visualization and retrieval tools and, among its many uses, it can assist in problem identification and in measuring the economic and environmental impacts of passenger and commercial vehicle delay.

with no additional data collection required. For other stakeholder-developed performance measures, data collection may be required.

In addition to vehicle probe speed data, other data sources may exist, but have not yet been fully utilized. For example, traffic signals with detection such as loop detectors can serve as a permanent count station if configured properly. ROP creators are encouraged to maximize use of existing data sources.

In some cases, the data needed for system performance monitoring is not currently available. For example, volume data corresponding to when congestion occurs is currently very limited. ROPs may consider deployment of data collection technology in order to improve the quality of data for future performance measures. If investment in new data collection is desired, the ROP should justify why existing data sources are insufficient.

Analyze Congestion Problems and Needs

Performance measures should be used to identify areas of concern and need within the transportation system. Identifying the source and location of the congestion plays a key role in determining the range of alternatives that will be considered to address these problems. Categorizing the subject roadway network using the TSMO Roadway Tiers (a classification system described later in this chapter) facilitates reporting measures, strategy needs assessment, and strategy prioritization. Performance measures should be reported at the regional and corridor levels.

Refer to Chapter 5 for additional details about classifying congestion and to better understand the congestion management needs of different regions and corridors.

Program and Implement Strategies

Prioritizing strategies, allocating funding, and programming projects within the TIP are the first steps towards advancing identified projects and strategies within the planning process and, ultimately, bringing them into reality. Refer to Chapter 6 for additional details on some of the TSMO Solutions which can be considered.

Evaluate Strategy Effectiveness

After strategies and projects are implemented, it is important to monitor and evaluate the success of those strategies. Knowing which strategies are effective, and in what specific situations, directly affects the future selection and assessment of strategies and helps to develop a data-driven process for benefit-cost analysis and decision making. FHWA's website has benefit-cost information for TSMO strategies.

Monitoring and evaluation typically includes: evaluating the effectiveness of implemented projects and strategies, tracking the overall system performance, and assessing and refining the objectives. Monitoring of performance is the responsibility of each user of the performance measures. For example, higher level monitoring will be conducted at a statewide level by PennDOT Central office, while regional monitoring of performance is the responsibility of the planning partners and the PennDOT Districts. Evaluation of previously-implemented strategies and further refinement of objectives is encouraged.

ROP Structure

It is recommended that the ROP be organized into the following eight parts:

1. Executive Summary (optional)
2. Chapter 1: Overview of the Region
3. Chapter 2: Existing Regional Demographics and Transportation Elements
4. Chapter 3: Existing and Future Operations
5. Chapter 4: Transportation Needs and Operational Issues
6. Chapter 5: Strategies and Projects
7. Chapter 6: ROP Coordination and Maintenance
8. Appendix

Tables and maps should be used extensively within the ROP to illustrate the content.

ROP Chapter 1: Overview of the Region

The introductory chapter of the ROP should include a high-level synopsis of the region, a list of the key stakeholders and their current activities, and the planning horizon for the ROP. The following lists provide examples of items to include within this chapter:

Synopsis of the Region

- Provide a description of the Region
- Provide a description of the jurisdictional boundary information of the region, while also identifying unique transportation and geographical features to be considered by the stakeholders.
- Produce a regional map illustrating the region's limits and key features.
- Identify the MPOs or RPOs that fall within the ROP Region boundaries and detail the current planning horizon time period to be used for the document, which should be consistent with the LRTP(s) planning horizon, if possible.

Key Regional Stakeholders

- Identify the key transportation stakeholders in the local, regional, State, and public safety agencies who will serve as the champions of the ROP. In a table, document the following information:
  - Organization name
  - Organization contact and contact information
  - Geographical coverage
  - Roles/responsibilities.

Example Stakeholder Outreach Activities:

- Meeting with existing transportation groups in the region to discuss transportation and operational needs
- Developing educational outreach materials
- Conducting surveys and workshops with stakeholders to discuss various components of the ROP

- Describe why each of the stakeholders is important to TSMO planning in the region.
- Document the current stakeholders' outreach activities in tabular form with the following information for each stakeholder and activity:
  - Organization
  - Activity Name
  - Activity Date
  - Activity Location
  - Summary of Activity Topics
  - Summary of Key Activity Results

Region's ITS and Operations Vision and Planning Process

- Provide a brief overview of the region's ITS and Operations vision taken directly from the LRTP(s).
- Document how the development of the existing and proposed ROPs was incorporated into the transportation planning process for the region.

  Chapter 1.0 of Advancing Metropolitan Planning for Operations, An Objectives-Driven, Performance-Based Approach, describes the federal requirements for coordinating transportation planning and operations and provides insight on the process. In addition to this federal resource, this Guidebook provides guidance on incorporating and building upon TSMO principles and utilizing TSMO tools in various planning efforts.

Acronyms and Abbreviations

Where acronyms and/or abbreviations are used in the ROP, they should have the same meanings that are indicated in at the beginning of this document.

ROP Chapter 2: Existing Regional Demographics and Transportation Elements

Chapter 2 of the ROP should illustrate existing conditions, considering the existing key transportation elements and background statistics.

Existing Key Transportation Elements

- Provide a brief overview of the region's transportation elements including major airports, seaports, interstates, as well as bus and rail transit.
- Populate a table with specific regional transportation demographics from the LRTP(s), including, but not limited to, the following information:
  - Population
  - Commuting patterns
  - Vehicle miles of travel
  - Roadway mileage and ownership
  - Corridors of significance
  - Intermodal facilities
  - Transit providers
  - Major tourist attractions
  - Major employment centers

TSMO Roadway Tiering System

As with any planning effort, it is important to define the scope of the roadway network. With input from statewide and District-level PennDOT representatives, as well as from planning partners, a roadway tiering system was developed to facilitate TSMO planning efforts, shown in Table 4.

The intent of the tiering system is to organize the roadway network into groups with similar characteristics and operational needs. This will help to consistently define expectations for management and operations across the state. While the National Highway System (NHS) roadway types are higher-order roadways with higher traffic volumes and will generally receive higher priority for operations planning and congestion mitigation, the tiering classifications are not intended to dictate specific solutions or levels of funding.

TABLE 4: TSMO ROADWAY OPERATIONAL TIERING CLASSIFICATIONS

Road Type	Tier	Criteria
Limited Access (NHS)	1A	AADT > 75,000
	1B	AADT between 50,000 and 75,000
	1C	AADT < 50,000
Non-Limited Access (NHS)	2A	AADT > 25,000
	2B	AADT between 10,000 and 25,000
	2C	AADT < 10,000
Non-NHS	3A	AADT > 10,000
	3B	AADT between 2,000 and 10,000
	3C	AADT < 2,000

The currently assigned roadway tiering is available in both static maps and interactive GIS formats. The tiering of the roadway system will be updated as travel patterns and traffic volumes change over time. Regions are encouraged to evaluate the TSMO roadway tiering as part of each ROP update cycle to determine if any overrides from the tiering calculated in accordance with Table 4 are appropriate based on corridor-specific functional and operational characteristics, especially for roadway segments where the AADT is near the boundary between tiers.

Corridors and Areas of Transportation Significance

- Provide a brief overview of the region's corridors and areas of transportation significance. These areas are defined as those that are important for the transportation of goods and services, and that significantly contribute to the economic sustainability and growth throughout the region. At a minimum, the corridors of significance should include all roadway segments within the region that are on the PA 511 core network. These significant corridors or roadways should also be classified using the statewide TSMO roadway tiering methodology.

- Populate the table with specific regional information that includes the following information (Table 5 below provides an example):
  - o Class of corridor or area (e.g., Rail, Interstate, State Route, Central Business District, intermodal center, etc.)
  - o Route Designation
  - o Corridor/area location/County
  - o Corridor/area usage (e.g., ridership, average daily traffic, etc.)
  - o Corridor/area significance (comments on the importance)
  - o TSMO Roadway Tier
  - o Indication whether the corridor is on the PA 511 Core Network
- Create a map(s) of the regional transportation network.

TABLE 5: SAMPLE TABULAR SUMMARY OF CORRIDORS AND AREAS OF TRANSPORTATION SIGNIFICANCE

Class	Route	County	Average Daily Traffic	TSMO Tier	511 Network	Notes and Considerations
Interstates		Cumberland Dauphin Franklin Lancaster Lebanon York	22-28K 27-32K 22-23K 28-38K 27K 28-32K	1C	Yes	• East-west toll facility connecting Philadelphia to Ohio • Significant commerce activity
		Lebanon	35-42K	1C	Yes	• East-west interstate connecting Harrisburg area to NY/NJ • Significant commerce activity and high truck percentages
		Cumberland Dauphin Franklin Lebanon	40-79K 55-92K 43-53K 30-55K	1A 1A 1B 1B	Yes	• Key north-south interstate corridor extending from TN to Canada • Significant commerce activity and very high truck percentages
		Cumberland Dauphin York	62-116K 70-116K 42-68K	1A 1A 1B	Yes	• North-south interstate connecting Harrisburg area to Baltimore • Provides connection from I-81 to I-695
		Dauphin	58-64K	1B	Yes	• East-west interstate connecting I-83 to PA 283 and PA Turnpike • Only approx. 5 miles long
U.S. Routes		Cumberland Franklin	2.7-35K 7.5-15K	2A 2B	Yes	• North-south route connecting south central and northeast PA • More localized traffic

Class	Route	County	Average Daily Traffic	TSMO Tier	511 Network	Notes and Considerations
Interstates		Adams Cumberland York	14-20K 33-48K 20-38K	2B 2A 2A	Yes	• More localized traffic in south central PA • Used as a primary route to NY and Canada

Regional TSMO Elements

- Provide a brief overview of the region's TSMO elements including, but not limited to, the following:
  - Closed circuit television (CCTV) cameras
  - Dynamic message signs (DMS)
  - Highway advisory radio (HAR)
  - Vehicle detection (VD)
  - Roadway weather information system (RWIS)
  - Ramp meters
  - Traffic signal systems (TSS)
  - Freeway service patrols (FSP)
  - Traffic Management Centers (TMC)
  - Traffic Incident Management (TIM) teams

  Refer to the list of TSMO Strategies in Chapter 6 for additional items to include.
- Populate a table with specific regional ITS elements. Resources include the LRTP, as well as stakeholders and PennDOT District personnel. Table 6 provides a sample of a tabular summary of existing ITS devices.
- Create a regional map(s) for each of the designated ITS elements.

TABLE 6: SAMPLE TABULAR SUMMARY OF REGIONAL ITS ELEMENTS

ITS Device	Interstates	Other Highways	Total
CCTV	68	45	**113**
DMS Permanent	25	11	**36**
DMS Portable/Semi-permanent	12	8	**20**
Loop Detectors	43	0	**43**
Microwave Detection	22	0	**22**
Video Detection	1	13	**14**
Ramp Metering	15	0	**15**
Traffic Signals	0	6,165	**6,165**
Traffic Signal Systems	0	165	**165**

Source: DVRPC ROP, 2007

ROP Chapter 3: Existing and Future Operations

Chapter 3 of the ROP should provide information documenting and summarizing the region's existing and future operations performance.

Existing Corridor Performance

- Provide a brief overview of the existing conditions related to:
  - Mobility (e.g., recurring and non-recurring congestion—delay)
  - Information (e.g., weather, incidents, events)
  - Safety (e.g., crash rates, crash clusters)
  - Organizational issues (e.g., maintenance, agreements, federal requirements)
- Quantify mobility performance following the procedures in Chapter 4 and Chapter 5 of this Guidebook in order to identify and classify congestion. It is anticipated that mobility performance measures will be derived through the PDA Suite and/or the PennDOT OneMap platform.
- Anecdotal evidence of operational performance issues should be avoided unless no other data sources are available.
- Prepare a map or exhibit (as applicable) for each corridor/area of significance, summarizes issues.

Precisely and numerically documenting the performance of the existing transportation system conditions is important for developing a basis for performance monitoring and future assessment. For example, it is not adequate to state that a corridor has a high crash rate; the actual crash rate of the corridor should be documented and then compared against regional, state, and national averages.

Recently Completed Projects

Performance measures can be used to document and monitor the impact of recently completed projects within the region. By quantifying the impact of different projects, ROP preparers can gain insight into which strategies are successful and begin to quantify the benefits derived from different types of projects. This information is useful for planning which types of projects to consider in the future. Before and after analysis is easy to quantify using the PDA Suite and available performance measures, as described in Chapter 4.

Planned Infrastructure Changes

In addition to capturing the existing transportation system condition, it is important to document planned infrastructure system changes. For example, the relative importance of a roadway corridor may change in the future due to changes in regional development or large-scale roadway projects. This information, including projections of future options when available, may be obtained from the LRTP, other existing regional planning documents, and stakeholders.

Future Land Use Changes

Future land use changes may cause significant changes to regional traffic operations. While individual land developments typically have localized traffic impacts, the ROP need only focus on those with a regional impact, such as large venues hosting special events or widespread changes in development trends which would impact regional traffic operations, such as freight/warehousing development patterns.

ROP Chapter 4: Transportation Needs and Operational Issues

Chapter 4 of the ROP should provide a high-level summary of the region's operational needs and issues. These needs and issues should relate to the goals and objectives. This chapter should also identify the roles and responsibilities of stakeholders and document any stakeholder agreements.

The purpose and needs statement in the ROP is important because it plays a key role in determining the range of alternatives that will be considered. Documenting regional needs and issues of the transportation system is important for selecting projects and strategies to implement. This is especially true in cases where the project is subject to other laws that require consideration of project purpose, such as Section 404 of the Clean Water Act and Section 4(f) of the U.S. Department of Transportation Act.

Regional Operations Issues and Needs

- Provide a brief summary for each high-level need or issue including the location, condition, and TSMO strategy being considered.
- Prepare several maps, exhibits or figures, if applicable, illustrating the region's transportation needs and operational issues. These should be based upon the analysis of existing conditions from Chapter 3 of the ROP. A sample of Organizational Needs map is shown in Figure 5.
- In addition to issues based upon the analysis of existing conditions, this section should also include identified future transportation challenges in the region. For example, anticipated growth in freight/warehousing land uses may increase freight traffic and result in future congestion.

FIGURE 5: SAMPLE ROP MAP – ORGANIZATIONAL NEEDS

Regional Operations Objectives and Performance Measures

- Develop objectives and performance measures based on the operational needs and issues identified in Chapter 3 of the ROP. The objectives should take into consideration the problem which needs to be solved, following the "SMART" characteristics:
  - Specific – The objective provides sufficient specificity to guide formulation of viable approaches to achieving the objective without dictating the approach.
  - Measurable – The objective facilitates quantitative evaluation, i.e. how much or how many or to what extent it should be accomplished. Tracking progress towards the objective enables an assessment of an approach's effectiveness.
  - Agreed – Planners, operators, and relevant planning participants come to a consensus on a common objective. This is most effective when the planning process involves a wide range of stakeholders to facilitate regional collaboration and coordination.
  - Realistic – The objective can reasonably be accomplished within the limitations of resources and other demands. The objective may still require substantial coordination, collaboration, and investment to achieve. Factors such as land use may have an impact on the feasibility of the objective and should be taken into account. Because the practicality of an objective cannot be fully evaluated until after strategies and approaches are defined, the objective may need to be adjusted to be realistically achievable.
  - Time-Bound – The objective identifies a time-frame within which it will be achieved (for example, "by 2022").
- Chapter 3.0 Developing Operations Goals & Objectives, in Advancing Metropolitan Planning for Operations, An Objectives-Driven, Performance-Based Approach, A Guidebook FHWA (HOP-10-026) provides additional examples of effective objectives.
- Populate a table with specific regional information consistent with the example in Table 7.

TABLE 7: SAMPLE ROP TABLE – OPERATIONAL OBJECTIVES

Operations Issue in Region	Operations Objective	Performance Measure
X% of congestion is recurring at bottlenecks due to demand exceeding capacity	Increase non-SOV mode share for all trips by X percent within the next Y years.	Share of trips by each mode of travel
X% of congestion in the region is caused by inclement weather. Snow, ice, and wind storms frequently cause severe delays, stranded vehicles, and crashes	Reduce time to alert travelers of weather impacts on travel (using dynamic message signs, 511, Road Weather Information Systems, public information broadcasts, etc.) by X time (time period or percent) in Y years	Time between the beginning of weather event and posting of traveler information on (select from among): dynamic message signs, 511, Road Weather Information Systems, public information broadcasts, etc.
X hours of congestion in the region is caused by traffic incidents	Reduce mean incident influence time per incident by X percent in Y years. (Defined as the time between awareness of an incident and the time travel returns to normal.)	Incident influence time.
X% of congestion in the region is caused by poor signal timing	Upgrade traffic signal technology to allow timings to adjust based on actual traffic conditions.	Percent of traffic signals on congested corridors upgraded every Y years.

ROP Chapter 5: Strategies and Projects

Chapter 5 of the ROP should identify the TSMO strategies and projects already on the LRTP as well as new strategies projects that are the result of the documented needs and operational objectives indicated in Chapter 4 of the ROP. These may be independently programmed projects or TSMO elements that are part of other planned/programmed capital projects on the LRTP and/or TIP.

Identify Strategies and Projects

- Describe the projects to be implemented within the region. TSMO strategies can be implemented as independent projects or as components of other projects. Refer to Chapter 6 of this Guidebook for some of the TSMO strategies which can be considered.
- Populate a table with specific project information that lists the goals, operational objectives, performance measure, strategies, and projects. Table 8 shows a sample of this table, taken from Advancing Metropolitan Planning for Operations, An Objectives Driven, Performance-Based Approach, A Guidebook (FHWA-HOP-10-026) Table 3.

Regional Project Maps

- Develop descriptions of the identified projects, followed by a map that identifies the proposed ITS and operations projects for the region.

Project Description

- Provide a project summary that identifies the goals, objectives, needs, and initial project costs.
- Populate a table with specific project information for each short-term project.
  For information on determining the expected benefits of ITS and operations projects, the ROP developer may refer to past documented experience and the FHWA ITS Joint Program Office website on ITS benefits (http://www.benefitcost.its.dot.gov/its/benecost.nsf/BenefitsHome).

Project Sequence

- Prepare and document a financial plan and identify the sequence of the proposed projects based on the planning horizon time line.
- Populate a table with specific project information, including estimates for capital, operations/maintenance (O&M), and life cycle replacement costs.
- Populate a table with specific project information for the highest priority projects that will occur within the first five (5) years of the plan.

Information and tools for determining project sequencing can be found in FHWA Regional Architecture Guidance, Version 2.0, Section 6.1.

TABLE 8: SAMPLE ROP TABLE – NEEDS AND PROJECT SUMMARY

Planning Process Stage	Examples			
Goal(s): Broadly describe what the region wants to accomplish, focused on outcomes	Improved transportation system reliability and reduced unexpected traveler delay			
Operations Objectives: Specific, measurable statements relating to the attainment of goals	Reduce incident-based delay so that by 2025, travelers experience no more than X hours of delay per year.	Reduce traveler delay associated with work zones, weather conditions and special events so that average buffer time is reduced by X minutes over the next Y years.	Increase awareness of traveler information by X percent to businesses and the public by 2026.	Improve transit system reliability so that by 2030, at least X percent of buses are on schedule.
Performance Measures: Measure used on a regional basis to track system-wide performance or at a corridor, roadway, or intersection level to identify deficiencies to address	Person hours of delay due to incidents.	Total vehicle hours of delay associated with work zones, weather conditions, and special events.	Public awareness of traveler information (through surveys).	Percentage of buses more than 5 minutes off schedule.
Strategies: Approaches to achieve objectives; includes system preservation, safety projects, management and operations, capacity expansion.	Traffic cameras and detection systems to identify incidents more quickly. Roving incident response teams.	Work zone information campaign. Dynamic message signs (DMS) to alert motorists of alternative routes.	Traveler alert system. 511 Traveler Information System. Electronic real time “next bus”information at bus stops.	Increased rail inspections and maintenance. GPS systems to track transit buses.
Projects/Implementation: Initiatives identified to carry out strategies.	Install traffic cameras onRoute X (2019). Install dynamic message signs on Route X (2023). Implement incident clearance teams on Route X (2022).	Implement regional electronic notification system (2025). Install VMS along key corridors (2023).	Install “next bus” signage at selected bus stops (2021).	Install GPS locator system for bus system (2026). Install “Next Train” signage (2021). Provide integrated train departure/arrival schedule for connecting buses (2022).

Project Dependencies

- Document any project dependencies that may impact deployment of the short-term priorities. Dependencies should be classified in terms of information dependencies, functional dependencies, and infrastructure dependencies.
  - Information flow dependencies refer to data required for a system to operate. For example, real time transit information to share with the public cannot be created until the data is collected on bus locations.
  - Functional dependencies include a relationship between two projects—for example; CCTV surveillance needs to be in place before incident verification can be performed.
  - Infrastructure dependencies are other transportation projects that may impact operations projects. Examples are the widening of a roadway or the rebuilding of an interchange that may affect existing ITS infrastructure or may need to be completed before ITS elements can be placed.

Project Deployment Plan

- Identify TSMO solution deployments for the first five years of the plan, by type of solution.
- Populate a table with specific project information.
- Create a regional map illustrating the deployment locations.

Stakeholders

- Identify roles and responsibilities of all stakeholders.
- Identify all agreements currently in place, as well as any new agreements that will be required to achieve the goals, needs, and service areas, as determined to be applicable for the region.

Monitoring and Evaluation of Project Implementations

Future iterations of the ROP will ideally include a monitoring and evaluation section that will evaluate the effectiveness of implemented strategies, track regional system performance, and assess and refine operations objectives. Chapter 6 of Advancing Metropolitan Planning for Operations, An Objectives-Driven, Performance-Based Approach provides guidance on monitoring and evaluation.

ROP Chapter 6: ROP Coordination and Maintenance

Chapter 6 of the ROP should identify when the ROP should be updated, who will maintain the ROP, and how the ROP is incorporated within the planning cycle for each planning partner within the region.

Synchronization with Other Planning Processes

- Create a regionally-specific ROP Update Cycle that will be in concert with the planning cycle process, considering the following:
  - The TIP is updated every two (2) years. To populate the TIP with operations projects, the ROP must contain a short-term planning horizon of five years that identifies yearly project deployments.
  - The ROP should be completed concurrently with the LRTP(s) or within one (1) year of completion of the LRTP. Depending on the region, LRTPs are updated every four or five years.
- PennDOT's statewide Device Deployment Plan, which combines all regionally planned and programmed statewide ITS deployment projects, is completed every year prior to the end of the State fiscal year.

Federal Compliance

The Federal Highway Administration adopted regulations, which are contained in 23 CFR Part 940, pertaining to conformance with the National Intelligent Transportation Systems Architecture and Standards pursuant to §5206(e) of the Transportation Equity Act for the 21st Century Act (TEA-21). Projects incorporating TSMO solutions that utilize federal funding are required to comply with 23 CFR Part 940. The ROP can fulfill the requirement to establish a regional ITS architecture.

Table 9 identifies how the recommended ROP structure complies with the FHWA requirements in 23 CFR 940. In order to serve as the regional ITS architecture, the ROP will require completion of the FHWA Compliance checklists which should be included within an appendix of the ROP.

Other federal laws contain requirements relating to transportation planning and the demonstration of need for projects, including the National Environmental Policy Act (NEPA), the Clean Water Act and Section 4(f) of the United States Department of Transportation Act of 1966 (Title 49 U.S.C.). ROPs can facilitate compliance with these laws by documenting the operational needs of the transportation system.

The needs identified in the ROP can then be incorporated by reference into required project-specific documentation.

TABLE 9: 23 CFR PART 940 CORRELATION TO ROP GUIDELINES

23 CFR Part 490 Reference	Regulatory Requirement	ROP Location
§940.5	Development of regional ITS architecture should be consistent with the transportation planning process for Statewide and Metropolitan Transportation Planning	Chapter 1
§940.9(a)	Provision should be made to include participation from the following agencies, as appropriate: Highway agencies, public safety agencies (e.g. police, fire, emergency/medical); transit operators; Federal lands agencies; State motor carrier agencies; and other operation agencies necessary to fully address regional ITS integration	Chapter 1
§940.9(d)(1)	Include a description of the region	Chapter 2
§940.9(d)(2)	Include identification of participating agencies and other stakeholders	Chapter 1
§940.9(d)(3)	Include an operational concept that identifies the roles and responsibilities in the operation and implementation of the systems	Chapter 4
§940.9(d)(4)	Identify any agreements (existing or new) required for operations,including at a minimum those affecting interoperability, utilization of standards, and the operations of identified projects	Chapter 5
§940.9(d)(5)	Include system functional requirements	Chapter 5
§940.9(d)(6)	Identify interface requirements and information exchanges with planned and existing systems and subsystems	Chapter 5
§940.9(d)(7)	Identification of standards supporting interoperability	Chapter 5
§940.9(d)(8)	Identify the sequence of projects required for implementation	Chapter 5

Chapter 4. Identifying Congestion

Since TSMO strategies are intended to reduce congestion and improve mobility, it is first necessary to determine congested locations to then determine where TSMO strategies may be beneficial.

Congestion occurs when the traffic demand exceeds the available capacity, and can occur if there is a surge in demand, a reduction in physical capacity, or a combination of both. Ultimately, the ratio of demand to capacity (commonly known as the volume to capacity ratio or v/c) must remain less than 1.0 to maintain uncongested conditions. Maintaining this balance of demand to capacity is critical to managing congestion since the extra turbulence of stop-and-go traffic reduces capacity through a bottleneck.

While the physical capacity of the highway system under normal conditions is relatively constant, capacity can be reduced due to work zones, traffic incidents such as crashes or vehicle breakdowns, and bad weather. Physical bottlenecks are locations where physical capacity is restricted with flows from upstream sections with higher capacities funneled into lower-capacity downstream segments. Manmade or intentional bottlenecks also exist, such as traffic signals and toll booths. Additional information regarding capacity, including adjustments due to temporary conditions such as incidents and work zones, is contained in the Highway Capacity Manual published by the Transportation Research Board.

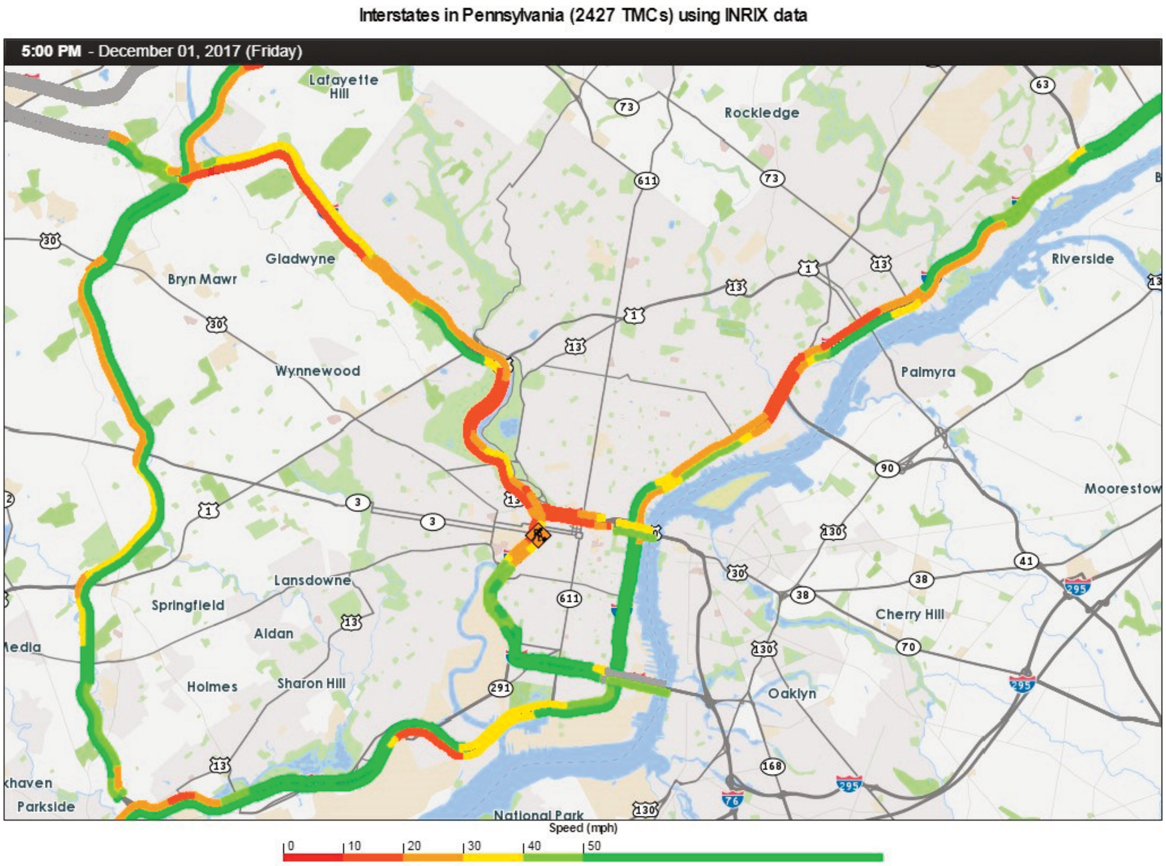
Identifying congestion involves the determination of the timing, location, and severity of existing congestion. These measures provide a baseline for evaluating changes in congestion as various TSMO strategies are implemented.

Methods to Identify Congestion

Congestion has both spatial and time dimensions. To visually identify congestion, a value must be picked for one dimension in order to see variation in the other dimension. For example, to see a map of where congestion occurs, one must first determine the time or range of time to be analyzed. Figure 6 shows congestion on interstate highways within the Philadelphia area at an instant in time. The congestion severity is measured by average speeds and is indicated by the color of the roadway.

Considering just travel speeds, there is significant congestion along I-76 and I-95 north of Center City Philadelphia, with some pockets of congestion at other locations.

FIGURE 6: MAP OF CONGESTED LOCATIONS

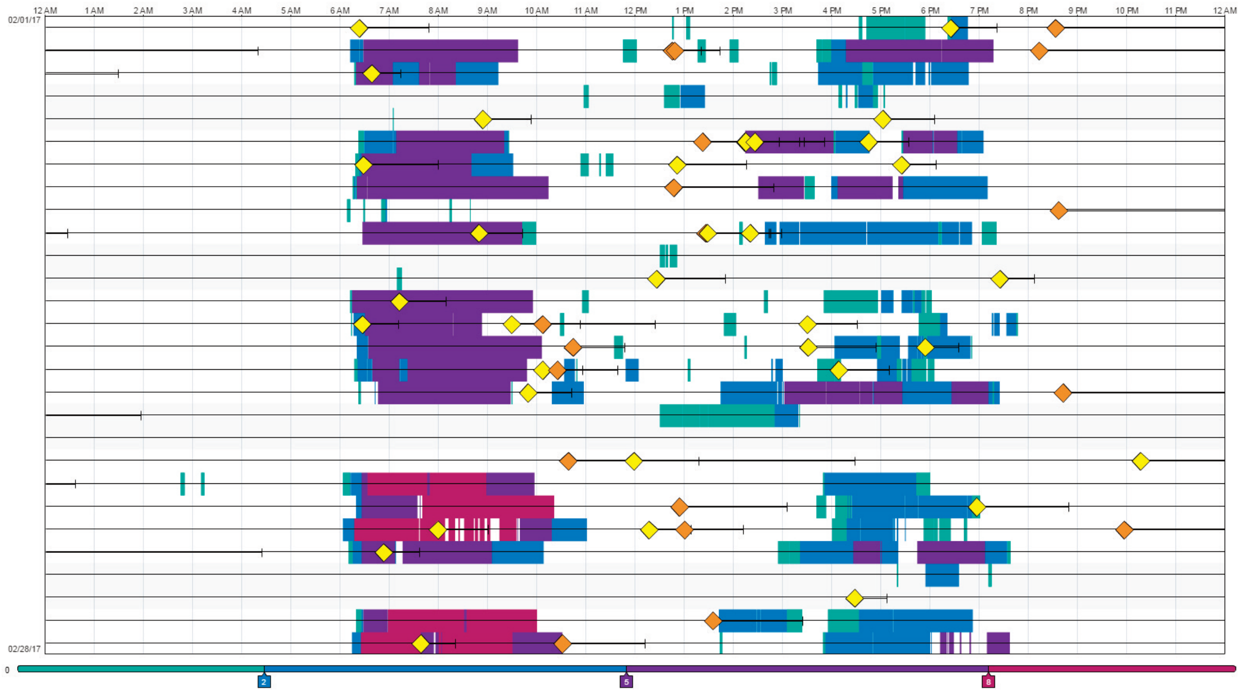


Source: PDA Suite, Trend Map

Similarly, a visualization for when congestion occurs could be a timeline for a particular roadway or region. Figure 7 shows a congestion timeline, generated from the Bottleneck Ranking Tool in the PDA Suite, for I-95 south at Exit 23/Girard Avenue in Philadelphia over the course of a month. The congestion severity is measured by maximum queue length and is indicated by the color of the bars.

The horizontal axis of Figure 7 represents the 24 hours in each day, with the vertical axis representing each day of the month. In this example, there appears to be recurring congestion weekday mornings from around 6:30 A.M. to 9:30 A.M. There is also congestion during the afternoon, but it is less predictable. The yellow and orange diamonds represent incidents and work zones, respectively.

FIGURE 7: TIMELINE OF CONGESTION



Queue Length (miles)

Source: PDA Suite, Bottleneck Ranking

Performance Measures

In order to incorporate objectives-driven, performance-based principles into planning for operations, appropriate performance measures must be selected to document and assess the current and/or past operation of the system or roadway of interest, and to set targets for future operations. PennDOT is making mobility performance measures available to assist with answering the following questions for statewide use:

- When is congestion occurring?
- Where is congestion happening?
- How intense is congestion?
- How reliable is travel time?

The questions above can be answered in some capacity in this first iteration of the TSMO program. PennDOT will move forward with obtaining data and developing methodologies for answering additional questions over the next few years, including the development of freight and transit performance measures. The intent is to standardize statewide and regional mobility performance measures that are available for use by PennDOT Central Office, PennDOT districts, and the planning partners. Performance measures feed the planning process, which is one of the dimensions of the CMM. Table 10 provides a list of the current performance measures.

The definition of the performance measures in Table 10 are described below, in detail, along with the method for producing the measures using the PDA Suite. Additional information on the calculation methodology is contained in the online help for the PDA Suite.

TABLE 10: CURRENT PERFORMANCE MEASURES

Measure	Questions Answered			
	When is Congestion Occurring?	**Where** is Congestion Occurring?	How **Intense** is Congestion?	How **Reliable** is Travel Time?
Time Delay	X	X	X	
Time Delay per VMT	X	X	X	
Delay Cost	X	X	X	
Delay Cost per VMT	X	X	X	
Travel Time Index (TTI)	X	X	X	
Planning Time Index (PTI)	X	X		X
Buffer Time Index (BTI)	X	X		X
Bottleneck Identification and Ranking			X	

Time Delay

Time delay is the amount of extra time spent traveling due to congestion, represented as total vehicle hours of delay. The PDA Suite calculates time delay using the "User Delay Cost Analysis" tool. Volume information is derived from PennDOT-collected average annual daily traffic (AADT) volumes, with hourly and daily adjustments applied to develop hourly volumes.

Time delay can be calculated using several options to filter which segments to include in the PDA Suite:

- Historic average speed – Delay is calculated for all segments whose raw speeds fall below the historic average speed for that segment. The historic average speed is specific to the time of day and day of week for each segment, and is calculated from the previous 2-years of historic speed data. This measure will show delay that is "worse than normal." An "offset" can also be specified, such as historic average speed minus 10 mph, and the result would be a delay for any time when speeds are 10 mph worse than normal congestion for each segment in the set.
- Free-flow speed – Delay is calculated for all segments whose raw speeds fall below the free-flow speed for that segment. Free-flow is the mean speed in mph (capped at 65 mph), and is calculated based upon the 85th percentile point of the observed speeds on that segment for all time periods. This measure will show delay that is "worse than free-flow." An "offset" can also be specified, such as free-flow speed minus 10 mph, and the result would be a delay for any time when speeds are 10 mph worse than free-flow.

- Absolute speed – Delay is calculated for all segments whose speeds fall below the speed value specified.
- For all segments – No segments are excluded.

PennDOT is seeking enhanced volume sources to improve this calculation in the future.

Generally, delay should be calculated for all segments whose raw speeds fall below the free-flow speed for that segment. In specific cases, using the other options may be appropriate, such as using a work zone speed limit to calculate delay through a work zone rather than the free-flow speed.

Time Delay per VMT

Time delay per VMT uses the time delay calculated above and divides it by the total vehicle miles traveled (VMT). The VMT is calculated by multiplying the hourly volume by the segment length.

Delay Cost

The user delay cost is calculated by multiplying the time delay by a cost per hour. The PDA Suite utilizes default values provided by the Texas Transportation Institute for the cost per hour, based on the passenger value of time and commercial operating cost. Users of the PDA Suite can also access other cost values.

Passenger delay cost is the product of passenger vehicle-hours of delay, the value of a person's time, and average vehicle occupancy. Commercial delay cost is the product of commercial vehicle-hours of delay and the commercial delay cost.

Delay Cost per VMT

Delay cost per VMT uses the delay cost calculated above and divides it by the VMT.

Travel Time Index (TTI)

Travel Time Index represents actual travel time as a percentage of the ideal (free flow) travel time.

$$\text{Travel Time Index (TTI)} = \frac{\text{Travel Time}}{\text{Free-Flow Travel Time}}$$

Planning Time Index (PTI)

Planning Time represents the total time a traveler should plan to ensure on-time arrival. The 95th percentile travel time is used for the calculation, meaning that if a traveler leaves the duration of planning time before they need to arrive, the traveler will arrive at or before the necessary time 95% of the time. Therefore, Planning Time is the near-worst case travel time.

The Planning Time Index (PTI) is a ratio of the near-worst travel time (95th percentile) to light or free-flow travel time. For example, a PTI of 1.60 means that, for a 15-minute trip in light traffic, the total time that should be planned for the trip is 24 minutes (15 minutes x 1.60 = 24 minutes) to ensure on-time arrival most of the time.

$$\text{Planning Time Index (TTI)} = \frac{\text{95th Percentile Travel Time}}{\text{Free-Flow Travel Time}}$$

Buffer Time Index (BTI)

Buffer Time represents the extra time (or time cushion) that travelers must add to their average travel time when planning trips to ensure on-time arrival. Buffer Time is different than Planning Time in that it compares the near worst-case (95th percentile) travel time to the average travel time, and the average travel time considers recurring congestion. Therefore, Buffer Time measures reliability due to nonrecurring congestion. It should also be noted that Buffer Time represents additional time required due to congestion, whereas Planning Time represents the total trip time.

The Buffer Time Index (BTI) is a ratio of the near-worst travel time (95th percentile) to the average travel time. The value of BTI increases as reliability gets worse. For example, a BTI of 0.4 (40%) means that, for a 20-minute average travel time, a traveler should budget an additional 8 minutes (20 minutes x 0.40 = 8 minutes) to ensure on-time arrival most of the time.

$$\text{Buffer Time Index (TTI)} = \frac{\text{95th Percentile Travel Time - Average Travel Time}}{\text{Average Travel Time}}$$

Bottleneck Identification and Ranking

Bottlenecks consist of congestion occurring on consecutive road segments and/or time. A road segment is considered congested if the reported speed falls below 60% of the free-flow speed. The PDA Suite identifies bottlenecks in a dynamic manner, allowing the bottleneck to grow, shrink, change locations, merge, and split apart over time, as further described in Appendix 1.

Although the PDA Suite uses the term bottleneck, the congestion identified with the Bottleneck Ranking tool includes physical bottlenecks as well as other sources of congestion. Depending on the time period selected for analysis with the tool, the bottleneck ranking may include non-recurring congestion such as winter weather, work zones, or incidents.

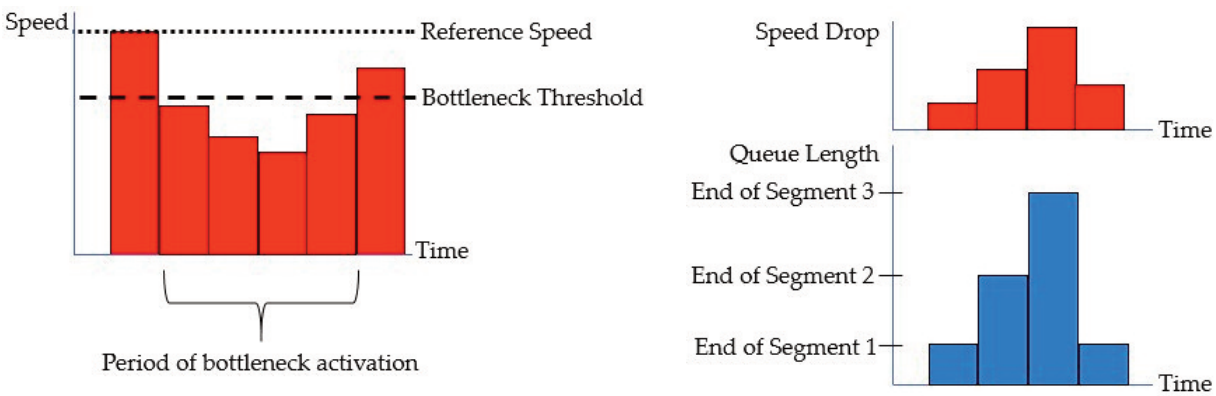
Queue lengths calculated in the Bottleneck Ranking tool are based on the length of TMC segments meeting the bottleneck activation criteria (60% of the free-flow speed). The reported queue doesn't always represent actual queue length, especially for longer TMC segments. For example, a 10 mile TMC segment could have 2 miles of stop and go traffic and 8 miles of free flow traffic, but the stop and go traffic is slow enough to bring the average speed for the entire 10 mile segment below 60% of the free flow speed.

The PDA Suite contains a Bottleneck Ranking tool which calculates bottlenecks and the associated attributes for a given analysis time period and location(s). The calculated attributes include:

- Average max length: The average maximum length, in miles, of queues formed by congestion originating at each location.
- Average daily duration: The average amount of time per day that congestion is identified originating at each location.
- Total duration: The total amount of time during which congestion was identified originating at each location.
- Base Impact: The aggregation of queue length over time for congestion originating at each location in mile-minutes. **PennDOT does not recommend using the Base Impact factor, as this doesn't consider volume and can rank low volume roads with speed variations and long segments inappropriately.**
- Speed Differential: The sum of raw speed drop, weighted by queue lengths for each time interval that the bottleneck is active within the analysis period.
- Congestion: The sum of speed drop, adjusted by bottleneck activation threshold (60% of free-flow speed) and weighted by queue length for each time interval.

Figure 8 shows how the speed drop is determined and weighted by the queue length during each time interval. The bottleneck occurs when the speed drops below the dashed bottleneck threshold line, which occurs for the four time intervals in the middle. The speed drop represents the difference between the bottleneck threshold and the actual speed, as shown in the upper right portion of Figure 8. The blue bars in the bottom right represent the queue length, which is calculated by adding the length of each consecutive TMC segment upstream of the bottleneck head which is below the bottleneck threshold speed.

FIGURE 8: SPEED PROFILE FOR BOTTLENECK CALCULATIONS



Source: PDA Suite Documentation

- Total Delay: The Speed Differential Factor, weighted by the volume estimate, considers raw speed drop, weighted by queue lengths for each time interval and the queue length.

Within the PDA Suite's Bottleneck Ranking tool, bottlenecks can be ranked by any of the attributes by clicking on the column heading. PennDOT recommends sorting the Bottleneck Ranking by the Total Delay column, as the volume weighting considers the number of travelers impacted by the bottleneck so bottlenecks on high volume roadways are ranked higher. PennDOT does not recommend using the Base Impact factor, as this doesn't consider volume and can rank low volume roads with speed variations and long segments inappropriately. However, users should be aware that segments for which no volume information is available will result in a total delay value of zero. Figure 9 shows an example Bottleneck Ranking produced from the PDA Suite, which is sorted by total delay (as indicated by the downward pointing triangle in the column heading).

FIGURE 9: BOTTLENECK RANKING TABLE

Bottleneck Ranking Table for 169 TMCs between January 1, 2017 and December 31, 2017 (93 total)

Display Options

			Bottleneck Profile			Influ...		Base impact weighted by			
Rank	Map	Head Location (approximate)	A...	A...	Total duration	All E...	Base L...	Speed diff...	Conge...	▼TOTAL DELAY	External Tool...
1	☐	I-80 E @ PA-38/EXIT 42	6.74	19 m	4 d 23 h 53 m	27	56,448.16	2,359,861.73	109,818.43	34,741,884,359.53	
2	☐	I-79 S @ US-6N/EXIT 166	6.46	23 m	5 d 21 h 43 m	60	57,234.21	1,788,240.44	71,985.77	19,656,338,923.78	
3	☐	I-79 S @ PA-198/EXIT 154	7.88	20 m	5 d 05 h 38 m	50	56,686.30	1,792,400.65	69,656.78	16,574,328,784.93	
4	☐	I-79 S @ US-322/US-6/EXIT 147	6.14	22 m	5 d 14 h 20 m	57	46,819.60	1,451,932.32	56,291.25	13,346,161,910.93	
5	☐	I-79 N @ ERIE--CRAWFORD COUNTY BORDER	10.69	11 m	2 d 20 h 38 m	27	42,875.17	1,311,001.85	50,170.96	11,426,692,167.95	
6	☐	I-90 E @ PA-89/EXIT 41	3.02	36 m	9 d 03 h 15 m	92	28,887.11	958,232.17	41,221.76	10,978,466,001.89	
7	☐	I-86 E @ PA--NY STATE BORDER	4.16	46 m	11 d 19 h 44 m	10	68,589.95	2,325,532.27	93,739.62	10,816,050,595.20	
8	☐	I-86 W @ I-90/EXIT 1B	4.54	37 m	9 d 10 h 24 m	2	62,113.88	2,112,995.36	85,692.15	9,827,541,442.17	
9	☐	I-79 S @ WEST RD/EXIT 174	3.29	22 m	5 d 14 h 49 m	41	25,442.15	793,322.62	32,567.42	9,816,574,056.89	
10	☐	I-90 W @ PA--OH STATE BORDER	6.05	9 m	2 d 10 h 21 m	75	26,536.97	890,077.43	35,006.84	9,751,688,296.80	
11	☐	I-79 N @ PA-198/EXIT 154	5.41	18 m	4 d 15 h 36 m	30	36,051.07	1,104,963.61	44,225.77	9,566,774,902.17	
12	☐	I-79 N @ US-322/US-6/EXIT 147	3.79	31 m	7 d 22 h 33 m	30	35,003.92	1,082,473.57	43,627.09	9,245,406,797.75	
13	☐	I-80 W @ PA-60/EXIT 4A	1.50	44 m	11 d 04 h 36 m	50	17,115.29	663,838.17	34,720.10	9,151,009,129.27	

Source: PDA Suite

Users should exercise caution when the bottleneck ranking tool identifies a bottleneck on a low-volume roadway, for the following reasons:

- INRIX may provide the historical average speed during low volume periods when there aren't enough probe readings, such as overnight hours. There are cases when the historical average speed is below the bottleneck threshold (60% of free-flow speed).
- On roadways where volume information isn't available, the resulting delay is zero due to multiplication by a zero volume. This typically occurs on roadways which aren't on the National Highway System.

Other Performance Measures

Stakeholders may find it useful or necessary to develop their own unique performance measures in addition to those in Table 10. There are limitations to performance measures that should be taken into consideration. These limitations include:

- Data: costs of data collection, quality/completeness of data (especially for multimodal), timeliness of data, and extraneous or unknown influences on data
- Analysis: extrapolating from partial coverage, matching measures to their purposes
- Results: liability for action (or lack thereof) based on measured results, use of measures in allocation of funding, responsibility for measures for which there may be limited control
- Coordination: conflicts with other measuring programs (e.g., which one takes precedence, etc.), assuring appropriate comparisons to other operations, consistency of benchmarking and targets
- Tools: availability of software tools to perform the analysis (for large data sets, spreadsheet-level analysis is not feasible)

Congestion Identification Tools

Probe Data Analytics Suite

The performance measures indicated in Table 10 can be generated through the University of Maryland's (UMD) Probe Data Analytics (PDA) Suite and Regional Integrated Transportation Information System (RITIS) using both real-time and archived probe speed data. PennDOT is currently purchasing the data from INRIX on an annual basis, covering major roadways throughout Pennsylvania. By purchasing this data and making performance measures available to PennDOT staff and planning partners, PennDOT makes it easier for performance to be consistently incorporated into the planning process and facilitates data-driven decision making.

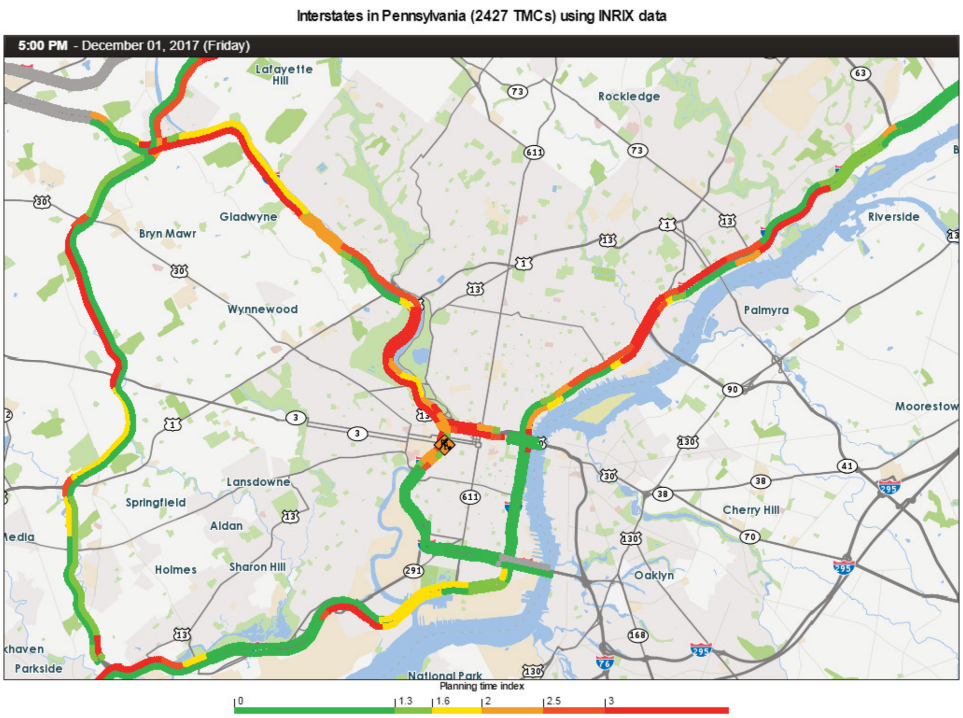
TABLE 11. PDA SUITE CONGESTION TOOLBOX

Measure	Congestion Scan	Trend Map	Performance Charts	Performance Summaries
Speed	X	X	X	X
Buffer Time			X	X
Buffer Index	X	X	X	X
Planning Time			X	X
Planning Time Index	X	X	X	X
Travel Time			X	X
Travel Time Index	X	X	X	X

The various tools within the PDA Suite can be used to generate measures as indicated in Table 11. Within the PDA Suite, graphics can be exported as images and data can be exported into spreadsheetcompatible formats for additional analysis. For graphic exports of charts, it is recommended to use a large pixel size if the chart will be printed, and a transparent background is recommended. When the export is in XML format, the files will not open in a spreadsheet program by default, but can be opened from within the spreadsheet application or by choosing "Open With" from the context menu.

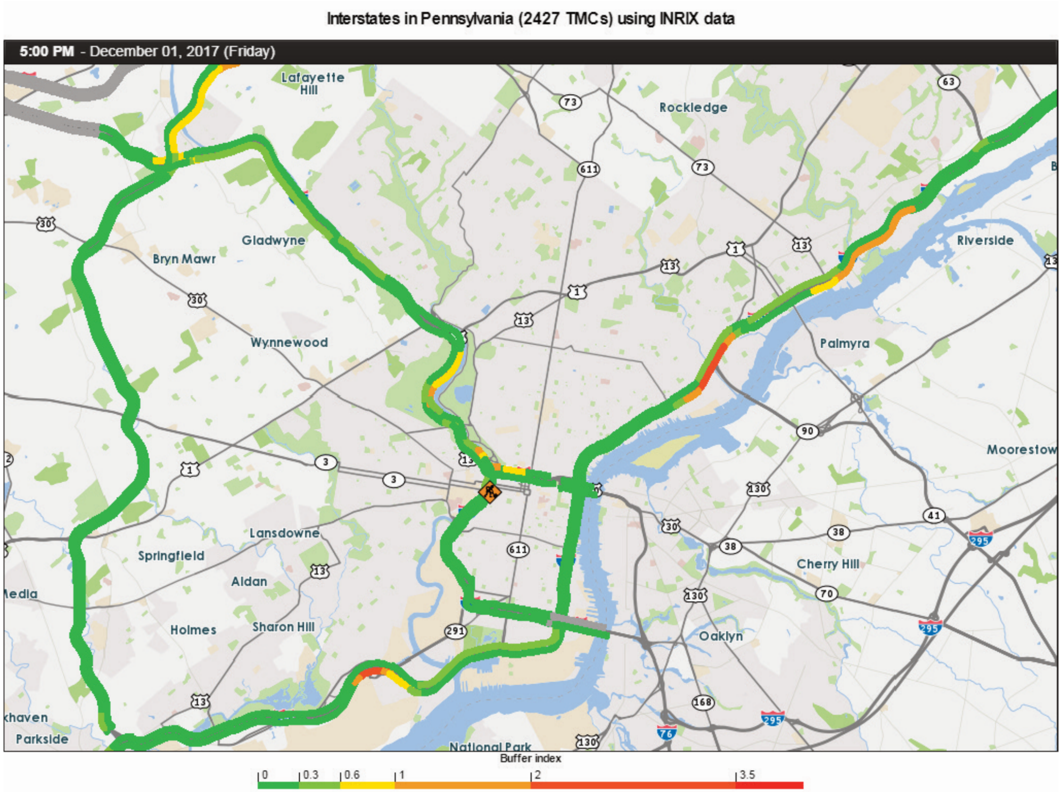
Figure 10 shows an example trend map with color coding representing Planning Time Index data for interstates within the Philadelphia region on a Friday at 5:00 p.m. Using the data on this map, travelers should plan for more than three times the free-flow travel time to arrive on time on many roadway segments on Friday afternoon (the darkest red segments). The Planning Time Index as shown on this map provides a good indicator of the intensity of congestion.

FIGURE 10: PLANNING TIME INDEX TREND MAP



Source: PDA Suite, Trend Map

FIGURE 11: BUFFER TIME INDEX TREND MAP



Source: PDA Suite, Trend Map

Figure 11 shows an example trend map with color coding representing Buffer Time Index data for the same region and time. Using the data on this map and comparing to Figure 10, the Buffer Time Index is relatively low for most segments, even where there is significant congestion indicated by the Planning Time Index. Although the travel times are high, the travel is reliable and travelers can expect their trip to be typical for a Friday afternoon.

TSMO Mapping

PennDOT has aggregated several traffic operations metrics for road segments across the state which are available through PennDOT OneMap. OneMap is a web-based interactive GIS mapping application, which includes GIS data from various sources across PennDOT plus additional operations data derived from probe speed data through the PDA Suite. OneMap can be used as a screening tool to identify congestion locations, estimate the cause of congestion using various data sources, and indicate if any TSMO strategies have already been deployed in the area. Various tools allow users to manipulate the data to show it in a variety of ways:

- Intersects data—Show where two sets of data overlap
- Themes data—Breaks out a data set into different groupings that are color coded
- Filters data—Only show data that matches certain criteria

PennDOT has developed three TSMO base maps in OneMap:

- Planned Events – Work Zones and Special Events
- Unplanned Events – Inclement Weather and Incidents
- Recurring Congestion – Bottlenecks and Signals

Each of the base maps correlates with one of the three external TSMO Program Goals. Accessing the TSMO base maps requires a login and TSMO-specific permissions, which can be obtained from BOMO. All of the maps contain bottleneck information, which is derived from the PDA Suite Bottleneck Ranking tool using INRIX probe speed data. Bottleneck data is provided for the previous 12-month period and refreshed monthly. The bottleneck layers only show the head segment of the bottleneck, as the tail may overlap with other bottlenecks making the map illegible. The bottlenecks are ranked by delay, with layers available for the top rankings by planning partner, PennDOT District, and RTMC region. Users should understand the limitations of the bottleneck methodology, as described earlier in this chapter.

Planned Events Base Map

The Planned Events base map is used to screen for congestion caused by work zones and special events. MPMS TIP data is included to identify when capital projects were in construction, which can be used as a surrogate for where work zones could have caused congestion. Special events entered in RCRS are also included as a default layer to identify where special events could have caused congestion.

Unplanned Events Base Map

The Unplanned Events base map is used to screen for congestion caused by inclement weather and incidents. Weather data is not currently available in OneMap. For incidents, statewide crash clusters and high crash locations from PennDOT's CDART system are provided as default layers. The statewide crash clusters are determined by CDART for a 5-year period and can be used to identify where frequent crashes may cause congestion. Crash clusters are provided for rear end crashes, intersection crashes, winterrelated crashes, and curved road crashes. The high crash rate layer includes locations where the segment crash rate per 100 miles is over 500 and the AADT is over 5,000.

Recurring Congestion Base Map

The Recurring Congestion base map is used to screen for overall congestion using bottleneck data. Although bottlenecks are the only default layer, users may also add traffic signal locations to identify where bottlenecks may be caused by traffic signals.

OneMap Examples

Figure 12 shows the statewide bottleneck data aggregated from the PDA Suite. This map shows that bottleneck data exists for nearly every segment statewide. This isn't helpful for TSMO analysis because it doesn't give the variability of how bad the congestion is at each location. The filtering tool can be used to see the top ranked bottlenecks in each RTMC region, PennDOT district, and planning partner region. As discussed earlier in this chapter, bottlenecks identified through the PDA Suite may include physical bottlenecks as well as other causes of congestion. Bottleneck data in OneMap includes the previous 12 months of data, so users should be aware of site-specific issues such as work zones that could affect the data.

FIGURE 12: STATEWIDE UNFILTERED BOTTLENECK DATA

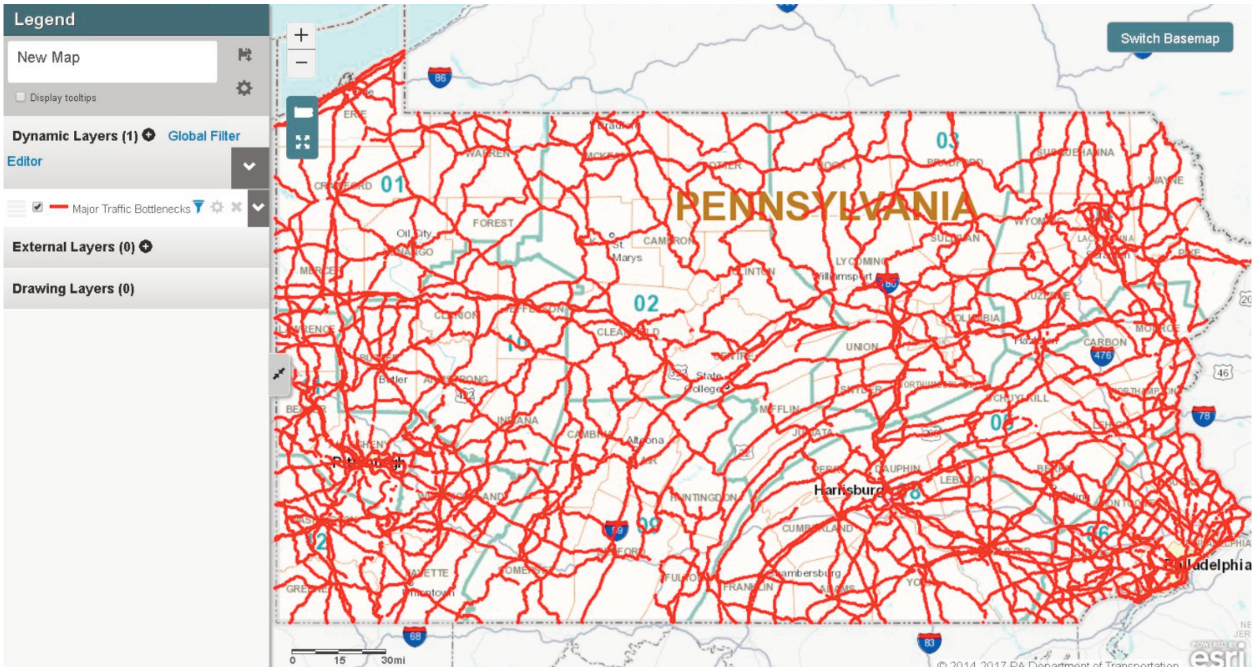


Figure 13 shows the top bottlenecks in the Central RTMC Region, with the top 10 bottlenecks shown in red, bottlenecks ranked between 11-25 shown in yellow, and bottlenecks ranked between 26-50 shown in blue. Figure 14 shows the area of the Central RTMC Region with the top 10 bottlenecks. In this case, the map can be panned and zoomed to the area of interest. Figure 15 shows a local view of the top bottlenecks in the Central RTMC Region. At this zoom level, road geometry and intersections with other roads can be visualized to understand the conditions which may be contributing to the bottleneck.

FIGURE 13: CENTRAL REGION TOP RANKED BOTTLENECKS

FIGURE 14: CENTRAL REGION TOP 10 BOTTLENECKS

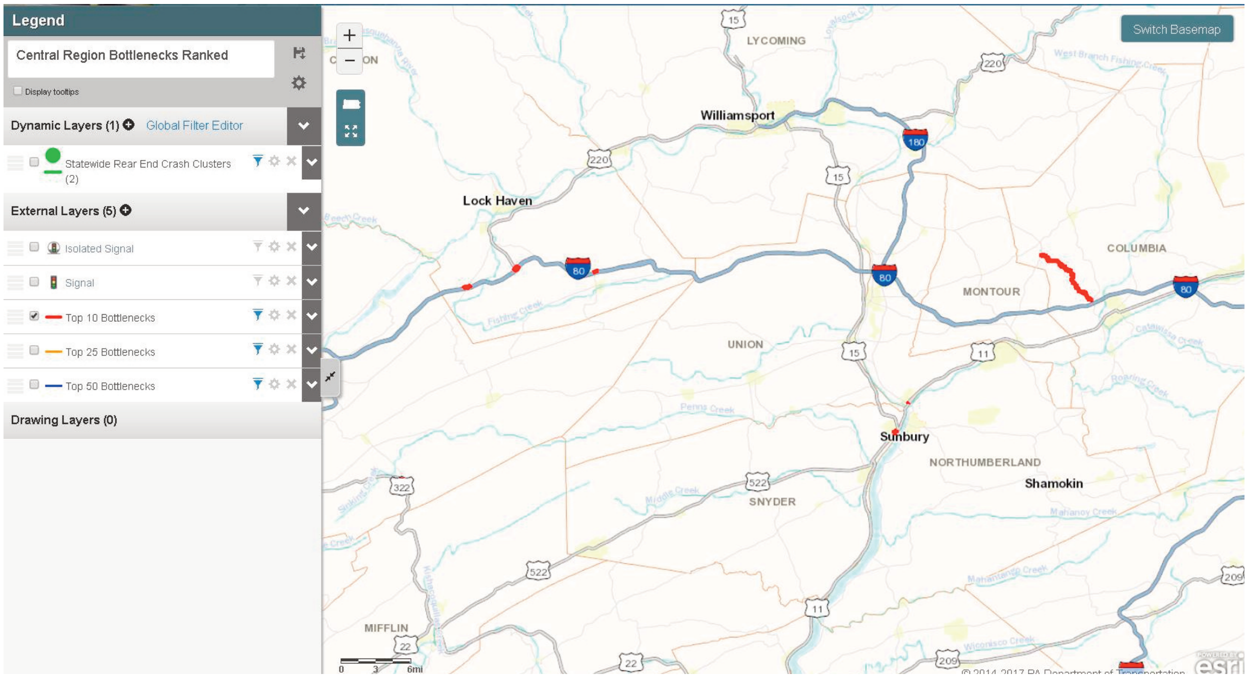
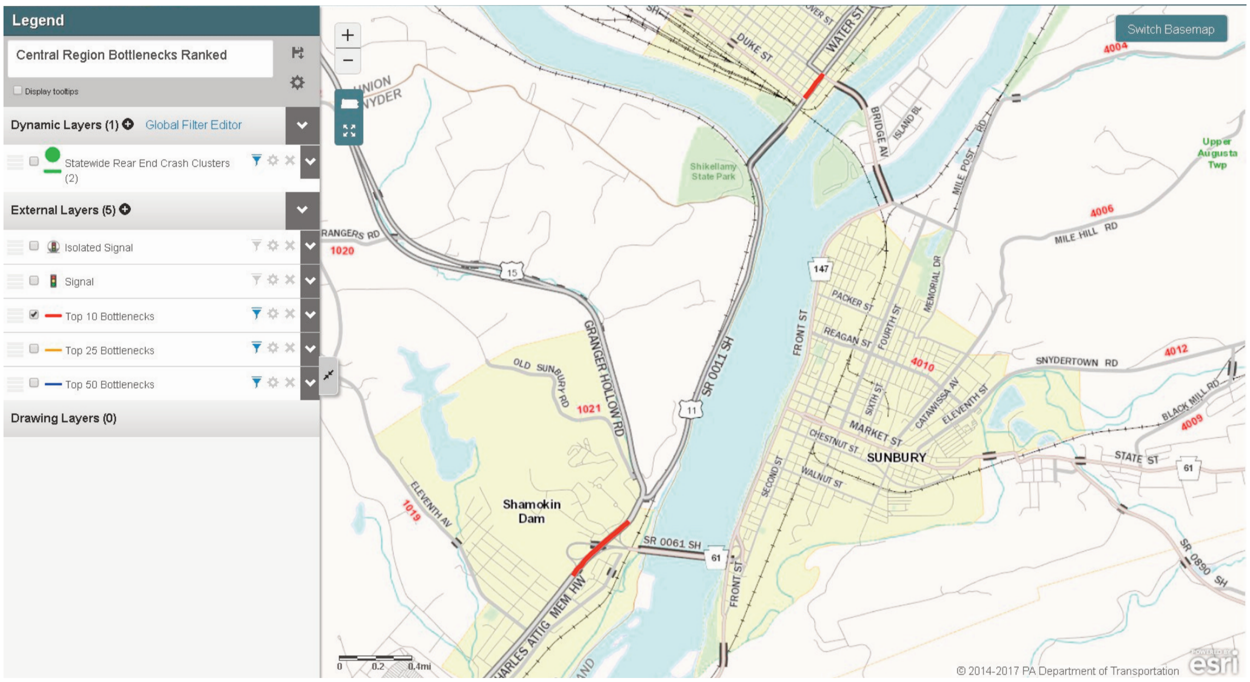


FIGURE 15: LOCAL VIEW OF TOP 10 BOTTLENECKS

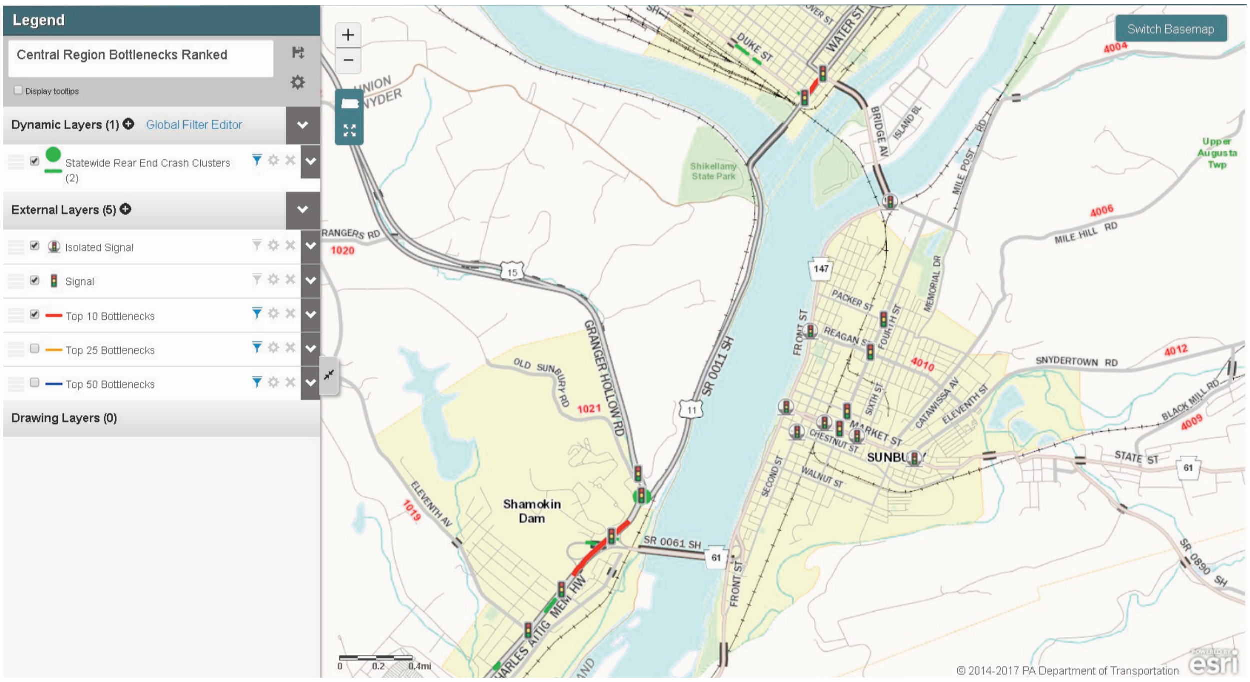


To further understand possible bottleneck causes, other data sources can be added to the map. In Figure 16, traffic signals locations from PennDOT's Traffic Signal Asset Management System (TSAMS) and rearend crash clusters from PennDOT's Crash Data Analysis and Report Tool (CDART) have been added to the map. Both of the bottlenecks in this map view are near traffic signals and clusters of rear-end crashes. It's likely the traffic signals contribute to the congestion, and the congestion in turn results in rear-end crashes.

This is a simple example of using the filtering and theming tools to manipulate data using OneMap. Other examples of how OneMap can be used include:

- A map that intersects a data set showing the locations where the Volume to Capacity Ratio is greater than one with another data set that shows the locations where paved shoulders have a width greater than 10.5 feet. This map could be used as a screening for potential locations where hard shoulder running may be effective and feasible.
- A map showing all ITS devices statewide could be themed to show the age of each device, giving the ability to see which areas need more attention for replacement of aging devices and devices past their expected life cycle.

FIGURE 16: LOCAL VIEW WITH SIGNALS AND REAR-END CRASH CLUSTERS



Chapter 5. Classifying Congestion

Once congestion has been identified, it is important to seek an understanding of the factors causing congestion or inefficiencies within a regional roadway system. The types of congestion affecting system performance can be initially categorized in one of two ways: recurring or non-recurring congestion.

- Recurring Congestion: what is expected and familiar to the motorist on a daily basis
- Non-recurring Congestion: result of circumstances that may not be expected by the motorist

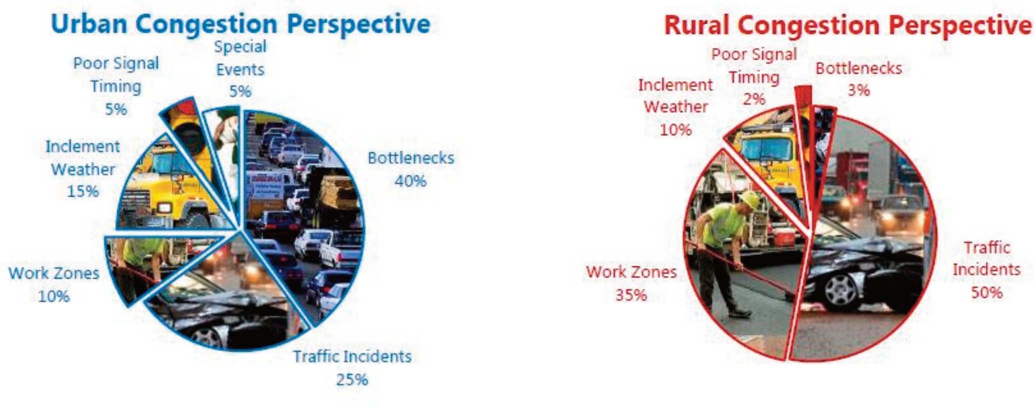
While there are many reasons for congestion, whether recurring or non-recurring, the FHWA has identified a number of broad congestion causation factors. Table 12 lists the primary recurring and nonrecurring congestion causation factors.

TABLE 12: RECURRING AND NON-RECURRING CONGESTION CAUSATION FACTORS

Recurring Congestion
Poor Signal Timing
Bottlenecks
Non-Recurring Congestion
Work Zones
Inclement Weather
Traffic Incidents
Special Events

As Figure 17 illustrates, the impact of the various congestion causation factors varies drastically between urban and rural highway systems. FHWA estimates that approximately 55% of congestion within an urban highway system is caused by non-recurring congestion causation factors, whereas in rural highway systems, non-recurring congestion causation factors account for approximately 95% of congestion.

FIGURE 17: NATIONAL CONGESTION PERSPECTIVES



Source: FHWA

Thus, to begin achieving PennDOT's TSMO mission, the state's TSMO planning approach needs to account for the various congestion causation factors and the differing geographical congestion needs across the state.

How to Classify Congestion

Each congestion event identified using the performance measures in Chapter 4 has one or more causes. While the exact cause(s) of every congestion event can be difficult to determine, a generalized pie chart, similar to those in Figure 17, can be developed for any region and/or corridor using a process of elimination method. PennDOT is seeking to develop tools to further automate this process in the future. Until the process is automated, completing a manual process to estimate the cause of congestion should be limited to the highest priority corridors, such as the corridors with the top 10 worst Bottleneck Ranking.

For the purpose of aggregating congestion classification, the quality of any specific data point will not significantly affect the results. Users should be aware of the limitations of various data sources and the method in which data is collected and exercise caution when applicable. For example, data sources which are human-populated, such as RCRS, may be susceptible to incorrect data entry.

First, the congestion should be categorized as recurring or non-recurring congestion. At the simplest level, recurring congestion can be assumed where the congestion speed is similar to the historical average speed for the segment provided by the probe speed data vendor. Otherwise, the congestion can be assumed to be non-recurring.

Recurring Congestion

Recurring congestion is either caused by a bottleneck or poor signal timing. Poor signal timing only occurs near signalized intersections, so the proximity to a signalized intersection can be used to determine whether the congestion is due to poor signal timing. If there is no signalized intersection nearby or downstream of the congestion, then the congestion should be classified as a bottleneck.

Non-Recurring Congestion

Non-recurring congestion can be a result of various types of events, including traffic incidents, inclement weather, work zones, or special events/other.

Traffic Incidents

Various sources of data can be used to identify potential incidents, such as the following:

- Road Condition Reporting System (RCRS) Event History
- Waze Alerts
- Crash reports

Inclement Weather

Historical radar data and/or precipitation gauge data can be used to determine if there was any precipitation or visibility restrictions such as fog. RWIS and RCRS can be used to determine pavement conditions and weather conditions.

Work Zones

The presence of a work zone can be determined from RCRS for major work zones.

Special Events/Other

Larger special events should be recorded within RCRS. Calendars of events for major venues should also be reviewed for major routes near the venue.

Other non-recurring congestion which cannot be classified as an incident, inclement weather, or work zone should be classified in the special events/other category.

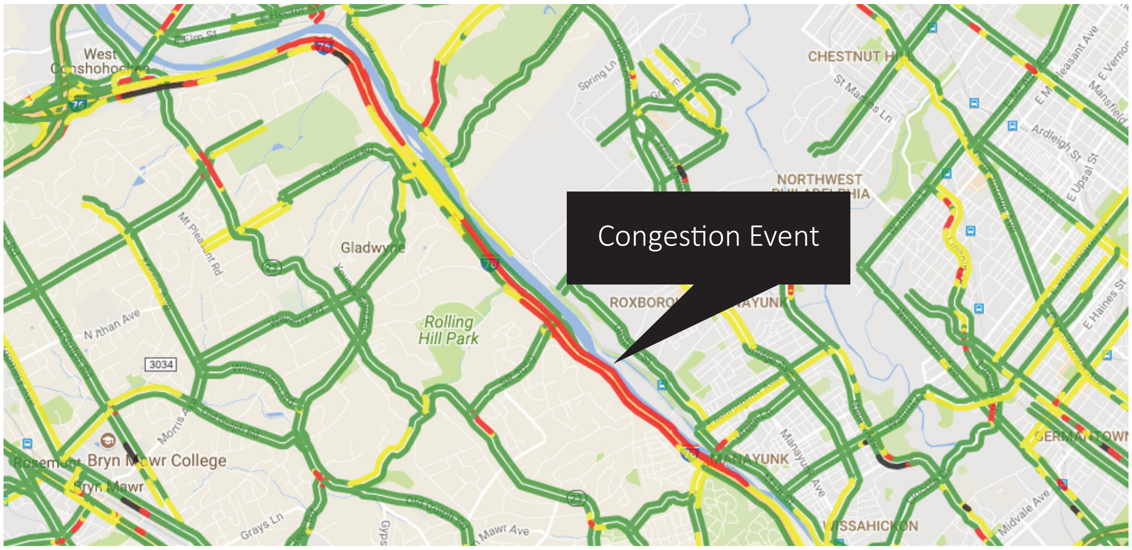
Example of Congestion Classification

As an example, a congestion event along I-76 westbound (Schuylkill Expressway) was identified on Sunday, July 30, 2017 at 5:00 p.m., as shown in the map below.

The first step is to determine whether the congestion is recurring on nonrecurring. Probe speed data contains historical average speeds for each hour of the day and day of the week, which can be compared with the actual speed. The historical average speed can also be compared with the free flow speed to determine whether there is typically recurring congestion.
Next, the different nonrecurring congestion factors are considered. RCRS data is overlaid on the congested area to determine if any incidents, weather, or work zones may have caused the congestion, as shown in Figure 19.

A multi-vehicle crash was reported. It is noted that the crash occurred on the opposite, eastbound side of the roadway, which may have cause rubbernecking for the westbound direction (for which we are exploring congestion). Therefore, this congestion event would be classified as a non-recurring traffic incident.

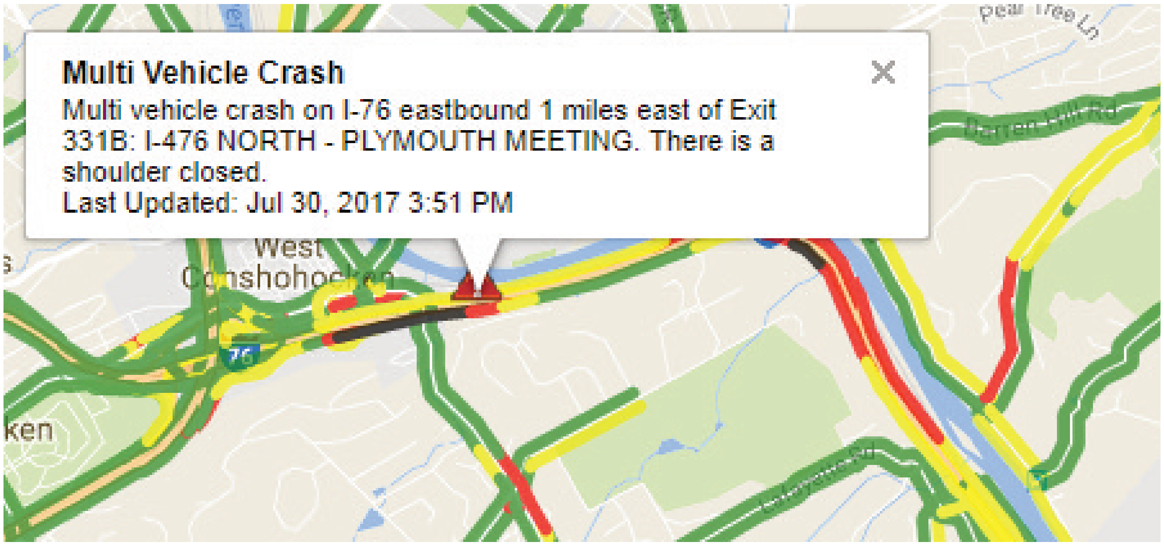
FIGURE 18: IDENTIFIED CONGESTION EVENT



Source: 511PA.com

PennDOT is seeking methods to automate the congestion classification process described in this Chapter. Until the process can be automated, it will only be feasible to classify congestion for top-ranked bottlenecks with a manual process.

FIGURE 19: NON-RECURRING CONGESTION FACTORS FROM RCRS



Source: 511PA.com

Chapter 6. Mitigating Congestion

Once the full picture of congestion is understood by identifying and classifying each instance of congestion, appropriate TSMO solutions can be considered candidates for a particular area. This chapter describes the various solutions in the TSMO toolbox, along with consideration for when these solutions should be considered. After determining which solution(s) are appropriate for a particular area, the design details for each solution can be determined in PennDOT's TSMO Implementation Guidebook Part II -Design.

Table 13 summarizes the applicability of each TSMO Solution in addressing the six causes of congestion.

TABLE 13: TSMO SOLUTION APPLICABILITY

TSMO Solution	Causes of Congestion					
	Recurring Congestion		Unplanned Events		Planned Events	
	Bottlenecks	Poor Signal Timing	Traffic Incidents	Inclement Weather	Work Zones	Special Events
Bridge De-icing				X		
Closed Circuit TV Cameras (CCTV)	X		X	X	X	X
Dynamic Curve Warning			X	X		
Dynamic Message Signs (DMS)	X		X	X	X	X
Dynamic Rerouting	X		X		X	X
Flex Lanes	X		X		X	X
Freeway Service Patrols			X		X	X
Integrated Corridor Management	X	X	X	X	X	X
Junction Control	X		X		X	X
Managed Lanes	X					
Queue Warning	X		X		X	X
Ramp Metering	X		X			X
Road Weather Info. Systems (RWIS)				X		
Smart Corridor Initiatives	X	X	X	X	X	X
TIM Teams			X			X
Traffic Incident Detection			X			
Traffic Management Center	X	X	X	X	X	X
Traffic Signal Enhancements		X				
Transit Signal Priority		X				
Traveler Information	X		X	X	X	X
Variable Speed Displays	X		X	X	X	

Bridge De-Icing

Various technologies can be used to prevent the accumulation of snow and ice on bridge decks in the case of inclement weather. Three different technologies can be used to transfer heat to bridge decks: hydronic (heated fluid pumped through pipe or tubing in the pavement close to the surface), heat pipe (passive transfer of heat by vaporization and condensation of a working fluid contained in sealed pipes), and electric (heat generated by electric resistance cables buried in the pavement near the surface). Another technology, fixed automatic spray technology (FAST) systems, provides a mechanism to apply chemical solutions to the roadway before ice can form.

Benefits

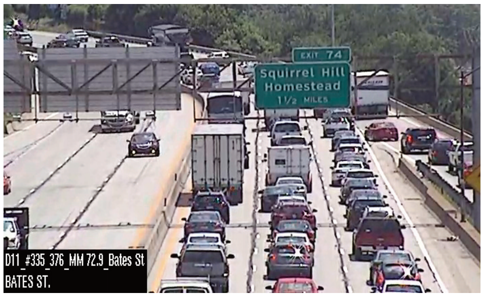
- Heating applications supplement or replace the use of chemical freezing point depressants, which only provide temporary protection, must be reapplied frequently, and can damage concrete bridge deck and structure over time (in the case of de-icing salts)
- FAST systems prevent ice prior to formation
- Enhances motorist safety
- Reduces traffic disruption

Elements Needed for Implementation

- External source (post-construction): passive transfer of heat by vaporization and condensation of a working fluid contained in sealed pipes above or below the bridge deck
- Internal source (pre-construction): heated fluid travels through pipes embedded near the surface of the bridge deck or electric cables buried in the pavement produce heat
- FAST systems require pavement sensors to determine when the system should be activated in addition to the infrastructure to store the chemical solution and apply it to the road surface

Closed Circuit TV Cameras

Closed Circuit Television (CCTV) cameras provide information that allows agencies to monitor and adapt traffic systems to current conditions and to track the effectiveness of management practices. CCTV cameras can be used in conjunction with radar detectors, inductive loops, and other traffic detectors for data collection along roadway facilities. Advances in video analytics may allow CCTV cameras to be used as the primary source of traffic volume data collection.



Benefits

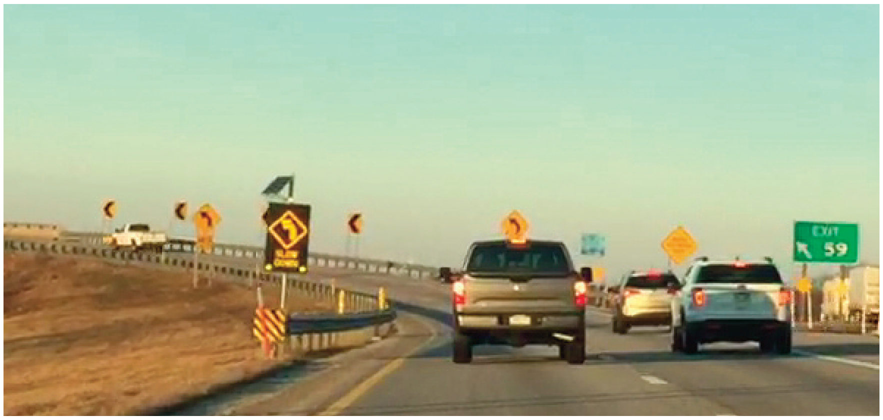
- Allow the TMC to monitor traffic and identify problems on roadways, including support of incident detection and traveler information systems
- Promotes more effective and efficient operation and management of roadways through agency-led real-time adjustment of traffic management tools
- Shortens incident response times and improves the appropriateness of the response
- Encourages better informed traveler decisions about how and when to travel, resulting in less delay to those travelers who use the information and lower overall congestion for all travelers

Elements needed for implementation

- CCTV equipment deployed along a roadway or network of roadways and connected with a traffic management center to enable fast and accurate information delivery
- Ability to view and process video feed in real time to be used for both traveler information systems and operational analysis
- Video analytics modules may be used to detect incidents using CCTV cameras and provide notification to TMC operators and/or take action regarding the potential incident

Dynamic Curve Warning

Dynamic curve warning provides feedback to specific vehicles which are approaching a horizontal curve at an unsafe speed. Approaching vehicles are sensed by radar or other ITS device and trigger the controller that activates the electronic sign elements to warn speeding drivers to slow down.



Benefits

- Improves safety on horizontal curves with frequent incidents caused by vehicles traversing the curve at high speeds
- Slows vehicles before they enter a curve to reduce crashes caused by speeding and driver error
- Improves the visibility of curves in poor conditions such as darkness and inclement weather

Elements Needed for Implementation

- Signs with associated flashing warning devices and/or blank out signs located approaching and/or within the curve
- ITS components, such as radar detectors, to sense vehicle and trigger the controller to activate the signs to flash sequentially through the curve

Dynamic Message Signs

Dynamic message signs (DMS) (also known as variable message signs (VMS) or changeable message signs (CMS)) are roadside or overhead signs with the capability to display different messages. Signs can either be permanently fixed in a single location or be mobile (typically trailer-mounted) in order to cover temporary conditions such as special events, traffic incidents, or road construction. Fixed signs should be used for locations where travelers routinely need information or before locations where travelers must make a routing decision.

Many DMS can be quickly modified in real-time from a central TMC location to provide current information. Traffic management centers can use DMS to inform travelers of incidents, travel times, detours, special events, and more. DMS are especially useful just before locations where travelers must take action or make route choice decisions. However, their message is limited to those who drive past the signs.

Benefits

- Allows travelers to make better decisions on the basis of communicated conditions, estimated travel times, and suggested detours
- Quickens the dispersal of information ahead of incidents, which can help travelers prepare for upcoming roadway conditions and reduce traveler frustration
- Improves traveler decision making, which can significantly improve safety, reduce congestion and travel delay, and decrease traveler frustration
- Improves the safety of the information delivery process, compared to the use of traffic websites and mobile device application, because in-vehicle use of cell phones is not required
- Provides public service announcements about distracted driving, impaired driving, seat belts, etc., when higher priority messages are not necessary

Elements Needed for Implementation

- DMS equipment deployed along a roadway or network of roadways and connected with a traffic management center to enable fast and accurate information delivery
- DMS placed well upstream of major interchanges to allow travelers time to reroute
- Use of clear and direct language to allow a quick and easy understanding of the message

Dynamic Rerouting

Dynamic rerouting is an active traffic management strategy that presents drivers with viable alternate routes when their normal route is severely congested due to incidents, special events, or other abnormal traffic conditions. The alternate route is determined based on prevailing traffic conditions along nearby highway routes between a given origin and destination. Alternate route information is typically disseminated using hybrid guide signs, DMS, or via broadcast media.

Benefits

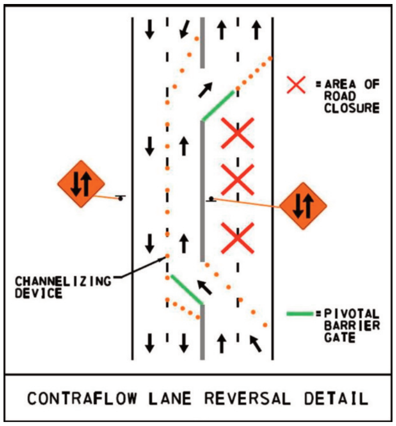
- Allows travelers to understand the impacts of current and expected congestion and travel times before trips and en route to make route choices for faster and more predictable travel times
- Reduces traveler delay and associated fuel use and emissions
- Reduces travel time and variability through better information about alternative routes and expected travel times
- Delays onset of congestion.
- Increases safety by decreasing the likelihood of secondary collisions during traffic incidents
- Improves the traveler experience as a result of better information and reduced uncertainty

Elements Needed for Implementation

- Devices to monitor existing conditions and software to estimate real-time travel times and congestion for multiple route alternatives
- Viable parallel corridors that have adequate capacity to serve as an alternate route with minimum negative impacts
- Traveler information systems to inform travelers of existing and expected conditions and/or travel times before trips and en route
- DMS used to provide dynamic rerouting traveler information will generally be larger and require a larger footprint for mounting, a designed structure, and an available 60 amp power source
- Connection with traffic incident management teams to quickly notify upstream travelers of lane and/or road closures

Flex Lanes

Flex lanes change the use of space within a corridor to accommodate changing travel demand at various times of the day. The various flex lane tools all involve repurposing the road infrastructure so that it is most effectively used where and when it is most needed. Methods include the following:



- Reversible lanes, which can be the middle lane(s) on an arterial or a separate (set of) lane(s) on a freeway, accommodate peak direction traffic during commute periods and enable detours around construction/maintenance, incident management, and special events. They are common on major bridge spans due to the large incremental cost of adding lanes.
- Contraflow lanes allow traffic lanes to be reversed on short notice, generally for emergency evacuations or incident management.
- Hard shoulder running, which is the conversion of shoulders to travel lanes during some hours of the day.

Benefits

- Reduces congestion by increasing the directional roadway capacity
- Allows multiple uses of existing infrastructure to provide capacity where and when most needed
- Reversible lanes and hard shoulder running postpone or replace the need to construct additional roadway capacity
- Contraflow lanes accommodate lane closures in response to unplanned special events and traffic incidents, and can be used for construction project phasing

Elements Needed for Implementation

- Management systems to describe when flex lanes are needed, such as automatic data collection (traffic volume sensors) or institutional measures (notification of special events)
- ITS components, including flex lane assignment equipment and the capability to safely and effectively operate it
- Redundant safety systems to ensure that flex lanes, especially when alternating between opposite directions of travel, do not allow simultaneous access from both directions
- Sufficient strength and quality of pavement and shoulder width to accommodate traffic

- Public outreach to ensure that users understand and will comply with flex lanes
- Automation to accommodate real-time demand; however, safety should be the primary goal

Additional information regarding Hard Shoulder Running can be obtained from Use of Freeway Shoulders for Travel – Guide for Planning, Evaluating, and Designing Part-Time Shoulder Use as a Traffic Management Strategy, FHWA Publication #FHWA-HOP-15-023, February 2016.

Freeway Service Patrols

Freeway service patrols (FSP) involve roving tow trucks systemically patrolling freeways and providing free assistance to motorists. For disabled vehicles, FSP provide basic services such as towing, jump starts, furnishing fuel, flat tire repair, and other minor repairs. FSP can assist relocating minor incidents off the roadway to ensure all travel lanes are opened. For major incidents, FSP can deploy temporary traffic control devices such as cones and an arrow board to safely divert traffic around incidents. FSP also handle other traffic disruptions, such as removing debris from the roadway.

Benefits

- Reducing incident duration and traffic delay
- Reducing cost of towing/assistance for motorists
- Increasing safety at incident locations
- Provide additional "eyes on the roadway" to verify incidents which are not visible to TMCs

Elements Needed for Implementation

- Fleet of tow-truck vehicles
- Highly trained personnel who can provide motorist assistance while maintaining safety
- Dispatch system for communications between FSP and TMC
- A public campaign explaining FSP and how motorists should take advantage of it

Integrated Corridor Management

Integrated Corridor Management (ICM) is a strategy to improve the movement of people and goods through institutional collaboration and integration of existing infrastructure along major corridors. Transportation corridors often contain underutilized capacity such as parallel roadways, unoccupied seats in vehicles, and parallel transit services which could be leveraged to improve person throughput and reduce congestion. ICM includes cooperation between the agencies in charge of signal operations, freeway operations, law enforcement, public transit, and traveler information to manage the corridor as a multimodal system and make operational decisions for the benefit of the corridor as a whole.

Phase 1

Phase 2

Benefits

- Improves corridor operations through better coordinated activities.
- Allows agencies to save money through the sharing of resources, which they can then reinvest back into other parts of the system.

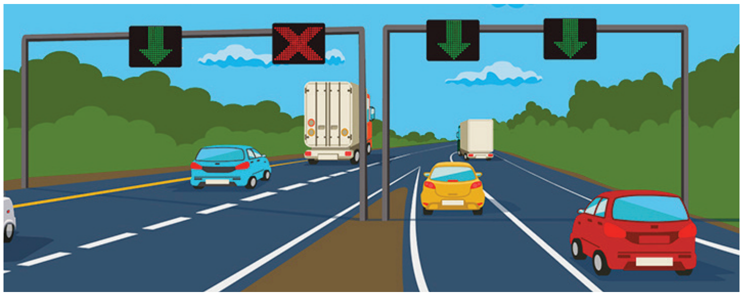
Elements Needed for Implementation

- Agreements between agencies and/or jurisdictions establishing professional relationships, supporting mutually beneficial strategies, and standardizing corridor management protocols.
- Streamlined practices and capabilities for sharing data, equipment, and expertise
- Regularly scheduled meetings among all relevant parties to discuss their joint use and/or management of corridors
- Sharing of data, training, communication equipment, and, in certain cases, personnel to improve corridor operations
- ITS device compatibility along jointly operated corridors
- Interconnectivity, compatibility, and/or integration between software platforms used to monitor the transportation system and control ITS devices; ideally a unified command and control software platform should be utilized

Additional information on Integrated Corridor Management can be obtained from FHWA's ICM Knowledgebase.

Junction Control

Junction Control, also known as Dynamic Merge Control, regulates or closes specific lanes on a freeway mainline upstream of an interchange areas where high traffic volumes are present and the relative demand on the mainline and ramps change throughout the day with different peak times.



Junction Control is most effective for facilities with underutilized capacity on the mainline lanes upstream of the interchange. Junction Control can also be used to provide a two-lane on-ramp with the left lane merging into the outside lane of the freeway. As an alternative, an additional on-ramp lane can be extended using the shoulder lane. At off-ramps, Junction Control can be used to create an Exit Only lane, such as when the queue on the ramp extends onto the mainline to separate through traffic from the queued traffic.

Benefits

- Allows multiple uses of existing infrastructure to provide facilities where and when they are most needed.
- Delays the onset of congestion by increasing capacity for the higher volume flow and encouraging more uniform speeds.
- Increases throughput by temporarily increasing capacity.
- Postpones or replaces the need to construct additional roadway capacity.

Elements Needed for Implementation

- ITS components, including dynamic lane assignment equipment, and the capability to safely and effectively operate it.
- Public outreach to ensure that users understand and will comply with dynamically assigned lanes.
- Automation to accommodate real-time demand; however, safety should be the primary goal.
- Management systems to describe when junction control is needed, such as automatic data collection (e.g., traffic volume sensors) or institutional measures (e.g., notification of special events).
- A bypass lane for emergency vehicles, transit, or other identified exempt users.

Managed Lanes

Managed lanes are freeway lanes operated using a variety of fixed and/or real-time strategies responding to local goals and objectives to move traffic more efficiently in those lanes, including High Occupancy Vehicle (HOV) lanes, High Occupancy Toll (HOT) lanes, Express Lanes, and Truck/Bus lanes. Managed lanes operate on the principle of managing demand by encouraging increased vehicle occupancy and/or incentivizing off-peak travel through implementation of tolls which are higher during peak periods. They are most effective for heavy freeway congestion that frequently affects travel time and travel time reliability.

Benefits

- HOV lanes encourage carpools, vanpools, and transit through time savings and improved reliability for vehicles in the managed lanes
- HOV lanes can also improve operations in general purpose lanes by promoting increased vehicle occupancy. For example, a 3+ HOV lane has the potential to replace 3 single-occupant vehicles in the general purpose lanes with only 1 vehicle in the HOV lane
- HOT lanes generate revenue to fund highway projects with additional managed lane capacity.
- HOT lanes increase the use of under-utilized HOV lanes, while maintaining HOV travel time reliability, by dynamically adjusting toll prices to limit demand to volumes that do not cause the HOT lane to become congested
- Express lanes can provide increased capacity by reducing the friction caused by closely spaced interchange ramps
- Bus lanes can be used to encourage transit usage and reduce single occupant vehicle travel

Elements Needed for Implementation

- Either the right-of-way on which an additional lane can be built or the ability to convert existing right-of-way (e.g., a wide shoulder) into an additional travel lane
- ITS components, including automated tolling and traveler information equipment to collect money and inform travelers of the price and conditions for eligibility
- Development of an enforcement system to identify and penalize violators

Queue Warning

Queue warnings alert travelers about downstream slow moving traffic, especially where drivers may not expect to encounter congestion. Queue warnings are typically disseminated through DMS; however, some advanced ITS applications involve in-vehicle queue warnings. Queue warning systems with portable DMS can be used ahead of work zones with lane closures in effect. Queue warning systems may be combined with variable speed limits to improve their effectiveness.

Benefits

- Reduces occurrences and severity of rear-end collisions by preparing travelers for congested conditions downstream
- Delays the onset of congestion through more uniform speeds and smoother traffic flow.
- Decreases emissions caused by stop-and-go driving
- Depending on placement of the warning, provides the opportunity and information for drivers to reroute around a queue

Elements Needed for Implementation

- ITS components, including strategically placed DMS visible to all vehicles and sensors to detect traffic flow near to and downstream of queue warning signs (to determine when such warnings are warranted)
- A traffic management center or inputs from sensors to make manual or automatic adjustments of the queue warnings

Ramp Metering

Ramp metering requires vehicles to stop at a signal on the freeway ramp before continuing onto the freeway. Typically, the meter allows one vehicle to pass per green light. Ramp metering reduces the merge conflicts that occur when platoons of vehicles enter the freeway, decreasing the impacts of those vehicles on mainline traffic flow. The mechanism for controlling the maximum flow of traffic onto a freeway is the length of the interval between green signals. Adaptive ramp meters adjust ramp flow on the basis of real-time freeway congestion and capacity—as well as arterial back-up from the ramp, in some cases—while fixed ramp meters work on a pre-set interval between green signals.

Ramp meters can be used 24/7 but are commonly used only during peak traffic periods. Ramp metering, when used properly, is one of the most effective strategies for freeway management.

Benefits

- Improves freeway flow and safety by delaying or preventing the onset of congestion by smoothing the inflow of traffic onto the freeway
- Limits the stress placed on freeways from traffic surges associated with special events or major traffic generators
- Increases the space between merging vehicles, allowing safer movement into freeway lanes
- Prevents or delays freeway capacity breakdown resulting from ramp inflow
- Adaptive ramp meters can reduce ramp delay as freeway demand subsides

Elements Needed for Implementation

- ITS components, such as ramp meter signals and vehicle detection equipment in the ramp and freeway lanes to measure traffic volumes
- Agency capability to install, calibrate, and monitor ramp metering equipment
- Coordination with the agency that operates the adjacent arterial (connected to the metered freeway ramp) on the operating rules and arterial impacts of the metering
- Ramp geometry needs to be reviewed to verify adequate queue storage space is available

Road Weather Information Systems (RWIS)

Weather conditions such as rain, snow, and cold temperatures can create unsafe roadway conditions for travelers. Road weather information systems (RWIS) monitor and report road weather conditions to provide travelers with road condition information so they can prepare for those adverse conditions or avoid them altogether. Important to these systems is the collection of weather data at critical locations that experience the most severe adverse weather conditions. Information about road weather can be disseminated through any of the traveler information data delivery channels, depending on locational availability. RWIS data can also be used as the basis for roadway operating decisions, such as the preparation of incident response, deployment of snowplows, de-icer applications, and even roadway closures.

Benefits

- Improves safety through traveler awareness and preparation for adverse conditions
- Heightens organizational preparedness for weather-related traffic incidents and improves decision support for control and treatment strategies
- Improves the understanding of roadway conditions' effects on roadway performance

Elements Needed for Implementation

- Measurement of weather conditions
- Prediction/evaluation of future weather conditions
- Ability to quickly disseminate information to travelers via appropriate advanced traveler information systems
- Integration of weather information into a traffic management center to streamline the analysis and dissemination of information

Smart Corridor Initiatives

Smart Corridor Initiatives, also known as Active Traffic Management, involve dynamic solutions to increase the efficiency of transportation facilities by focusing on trip reliability. Smart Corridor Initiatives may employ other TSMO strategies described in this guidebook. Integrated systems with new technology are used to optimize system performance quickly and without delay that occurs when operators must deploy TSMO strategies manually.

For example, traffic signal timing traditionally operated with time of day plans would instead include adaptively adjusted traffic signal timings based on real-time traffic flow conditions. When operated in an integrated system with other strategies, the traffic signal system could adjust signal timings knowing that an incident just happened on a parallel freeway which will increase demand on the signalized arterial. Smart Corridor Initiatives are more dynamic in nature than other, more traditional TSMO approaches described in this document.

TIM Teams

Traffic Incident Management (TIM) is a multi-agency, coordinated effort to minimize the impact of traffic incidents, often championed by planning partners. TIM requires the planning and coordination of multiple entities, including relevant transportation departments, law enforcement, fire departments, emergency medical services, towing and recovery companies, and hazardous materials clean-up contractors. Each of these agencies have diverse priorities and cultures which need to be addressed through a unified set of TIM strategies including better interagency coordination and training. Successfully executed TIM requires strong interagency relationships, focused and clear incident response goals, and a formalized TIM team and process that clarifies the roles for each entity.

Benefits

- Reduces total incident response cost through improved incident response resource sharing
- Decreases travel delay and improves safety through faster incident clearance
- Improves communication between response agencies

Elements Needed for Implementation

- Formalized TIM process that clarifies each agency's role in TIM
- Implementation of performance metrics to provide measurable TIM goals, such as response time and clearance time
- Routine coordination meetings among agencies involved in the detection, response, and recovery of traffic incidents
- Regular training and post-incident debriefings with all responders to ensure that all parties are prepared for their roles and to identify areas for improvement in the TIM process
- Joint incident management center or communications protocol to connect all agencies and provide centralized dispatch

Traffic Incident Detection

Early and accurate detection of traffic incidents allows authorities to respond more quickly to the scene of an incident with appropriate personnel and equipment. Traffic incidents may be detected by individual calls to 9-1-1, by loop detector data indicating a major slowdown, by closed-circuit TV (CCTV) cameras, by patrolling officials, by probe speed data such as INRIX, by crowd-sourced data such as Waze, and/or by automated collision notification systems. Incident detection informs authorities of the existence of an incident, while incident verification informs them more precisely of the nature and location of the incident.

Benefits

- Improves the speed of incident identification, incident deployment, and incident response.
- Improves the appropriateness of the response through enhanced information.
- Reduces the likelihood of secondary incidents by decreasing the amount of time that incidents remain uncontrolled.
- Improves outcomes through enhanced response to incidents on less trafficked roadways.

Elements Needed for Implementation

- Frequent and enhanced roadway markers and automated caller positioning systems (also known as location referencing system), which provide points of reference for 9-1-1 dispatchers relaying incident information.
- ITS components, including CCTV cameras and a comprehensive network of loop detectors with incident detecting algorithms, which can indicate slower than usual travel speeds resulting from incidents.
- Communication protocols with patrolling law enforcement officers and closed circuit television systems to provide faster initial incident response and verification.

Traffic Management Center

Traffic management centers (TMCs) operate as mission control centers for transportation operations. TMCs oversee traffic signal systems, traffic incident management, and traveler information strategies to ensure that roadways operate smoothly. TMCs proactively deploy traffic management strategies and coordinate interagency responses to special events, traffic incidents, and recurring congestion.

TMC operators monitor CCTV cameras and operate ITS devices.

Benefits

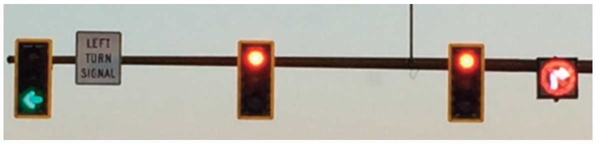
- Streamlines multi-agency traffic operations and traffic incident management.
- Allows for constant monitoring of traffic operations data.
- Provides the ability to observe system-wide operations, quickly identify congestion and traffic incidents, and quickly implement detours and travel time predictions.

Elements Needed for Implementation

- Centralized control of ITS components, including traffic signal and other corridor operations, as well as all data monitoring capabilities.
- Capital and operational funding to implement and sustain a TMC, ideally through dedicated and consistent funding sources.
- Investment in compatible signal systems across the jurisdiction and advanced transportation management systems to make the TMC more effective.

Traffic Signal Enhancements

Traffic signals can improve the safety and efficiency of roadway networks for motorists, cyclists, and pedestrians. However, poor signal timing and/or poor signal coordination can diminish the effectiveness of the signals. Traffic signal enhancements allow agencies to get the most effective operations from their signals.



Examples of traffic signal enhancements include:

- Optimization and coordination of signal timing
- Integrating signal systems across adjacent jurisdictions to improve arterial progression
- Adaptive traffic signal control to smoothly adjust timings to account for actual traffic volumes where volumes are less predictable
- Traffic responsive operations for corridors where traffic volumes fall into typical patterns, but the volumes vary daily
- Emergency vehicle preemption to halt general traffic movements so that emergency vehicles may pass through
- Removal of unwarranted traffic signals
- Monitoring traffic signals using automated traffic signal performance measures developed from high resolution data logs

Benefits

- Decrease congestion and delay, improving travel time and travel time reliability.
- Smoother traffic flow and reduced congestion between traffic signal systems in adjacent jurisdictions.
- Improve safety without major modifications.

Elements Needed for Implementation

- ITS components for signal coordination, integration, emergency vehicle preemption, and ATSC.
- Communication protocols between stakeholders for coordination of signal operations.

Transit Signal Priority

Transit Signal Priority (TSP) can either extend green times or shorten red times upon receiving a priority request signal from transit vehicles. This allows them to move through a corridor more efficiently, ultimately providing faster service with improved reliability without causing significant delay to other vehicles on that arterial. TSP does not automatically allow transit vehicles passage (that is transit vehicle preemption); instead, the TSP programming considers a variety of factors such as congestion, the current signal cycle phase, and the transit vehicle's current adherence to its schedule. TSP can be considered at intersections where transit vehicles routinely experience delay or travel time variability.

Benefits

- Reduces transit vehicle travel time, particularly the average speed of slow bus routes, which reduces the operating costs of those routes and decrease riders' travel time. This also allows transit to compete more effectively with SOV driving.
- Decreases travel time variability through intersections, helping transit vehicles adhere to their schedules and reducing the need for slack time at the end of routes.
- Increases intersection throughput because of the large capacity of transit vehicles and potentially reducing the number of SOV.
- Reduces operational costs for the transit provider with increased efficiency as well as potentially increasing ridership and revenue.

Elements Needed for Implementation

- Coordination between the signal operating agency and the transit agency to develop a TSP system.
- ITS components that include the following four elements:
  - o Transit vehicle detection system (both vehicle-based emitters and infrastructure-based receivers
  - o Priority request system to notify the signal when the transit vehicle requests priority
  - o Priority control strategies to determine which transit vehicles should receive priority
  - o Signal software technology to manage and process requests and store data
- Institutional training to operate and maintain a TSP system.

Traveler Information

Traveler information is intended to enable current or potential travelers to make better informed decisions about the route they take, the time they leave, and the mode they choose. Useful information can include road/weather conditions, travel times/speeds, transit vehicle arrival times, parking availability, construction/detour alerts, and much more. Traveler information includes road signs and maps, as well as advanced traveler information systems (ATIS) utilizing ITS components to collect, process, and deliver traveler information, typically in real time, including:

- Use data collected from agency systems, private sector vendors, transit vehicles, and more to provide travelers with accurate, real-time travel information for their en-route or pre-trip decision making.
- Provide travelers with information—via dynamic message signs (DMS), smartphone apps, conventional websites, radio and TV announcements, and more—that allows them to make better informed travel decisions.
- Relay specific detour instructions to avoid traffic incidents, special events, and construction zones.
- Improve transit service by giving riders a better idea of when their transit vehicle will arrive.
- Tailor information delivery for travelers already en-route and for those making pre-trip decisions.

Benefits

- Better informed traveler decisions about how and when to travel, resulting in less delay to those travelers who use the information and lower overall congestion for all travelers.
- More effective and efficient operation and management of roadways through real-time agency adjustment of traffic management tools.
- More efficient transit services with accurate transit arrival time and routing information.
- Reduced driver frustration and anxiety through better knowledge of current conditions.
- Safer driving behavior through better pre-trip and en-route information about detours.
- Greater demand for transit and reduced travel demand by personal vehicle due to better transit arrival time information.

Elements Needed for Implementation

- Data collection technology (loop detector, CCTV, weather monitoring stations, pilot vehicle GPS).
- Ability to store and process data for both traveler information systems and operational analysis.
- A traffic management center (TMC). The activities of a TMC (monitoring highway operations, controlling traffic signal systems, and coordinating emergency response teams) provides much of the same data/information needed to update and disseminate traveler information.
- Information dissemination platforms, which may include en-route signage, public platforms such as TV and radio, and on-demand services such as 511 and DOT websites.

Variable Speed Displays

Variable speed displays, also known as variable speed limits, are posted by variable message speed limit signs. Variable speed limits can be changed remotely by a TMC or automatically in response to congestion, incidents, work zones or road weather conditions. Variable speed displays may be used to slow vehicles before they enter an area of slowmoving traffic to reduce rear-end collisions and maintain traffic flow.

Benefits

- Delays the onset of congestion by adjusting upstream speeds to better match downstream speeds and by slowing travelers before and through adverse conditions.
- Improves safety by lowering speed limits to a value that better reflect current conditions and by reducing the risk of secondary incidents when used as a part of traffic incident management.
- Reduces emissions caused by stop-and-go traffic.

Elements Needed for Implementation

- ITS components, including:
  - o Adjustable speed limit signage and control technology
  - o Devices to monitor traffic conditions along a freeway corridor to change speed limits and observe compliance
  - o Devices to monitor weather and road conditions to adjust speed limits for rain, ice, and low visibility
  - o Provision of traveler information that justifies the speed limits and enforcement of them to ensure driver confidence and compliance

Chapter 7. Federal System Performance Measurement

In 2012, the Moving Ahead for Progress in the 21st Century Act (MAP-21) (P.L. 112-141) was enacted. MAP-21 established the framework for defining national performance goals for the transportation network and created a performance-based, multimodal program. Rulemaking by the Federal Highway Administration (FHWA) regarding system performance (known as PM3) was issued January 18, 2017 and took effect May 20, 2017. This rulemaking defined the required congestion performance measures, a compliance timeframe for agencies to provide measures, and measure targets.

MAP-21's program puts a focus on performance and outcomes-based planning. The intent is to increase accountability and transparency of the Federal-aid highway program and improve project decision making through performance-based planning and programming.

In December 2015, the Fixing America's Surface Transportation (FAST) Act (P.L. 114-94) was signed into law to provide long-term funding certainty for surface transportation infrastructure planning and investment. The FAST Act builds on the reforms made by MAP-21 by incorporating revisions aimed at ensuring the timely delivery of transportation projects. The FAST Act continues to support the performance goals, measures, and targets set in MAP-21 and enhances these reforms through the inclusion of new provisions.

The purpose of this chapter is to summarize PennDOT's approach to comply with the PM3 final rulemaking from the FHWA, for the performance measures which are derived from probe speed data. The information contained herein is based upon a review of Federal Regulation and associated documentation provided by FHWA in the Docket and Federal Register. It is anticipated that this chapter will continue to be updated as additional information and guidance is provided by FHWA.

Background

MAP-21 and the FAST Act set national goals for performance measurement relating to the following traffic operations areas:

- Congestion reduction – to achieve a significant reduction in congestion on the NHS.
- System reliability – to improve the efficiency of the surface transportation system.
- Freight movement and economic vitality – to improve the national freight network, strengthen the ability of rural communities to access national and international trade markets, and support regional economic development.
- Environmental sustainability – to enhance the performance of the transportation system while protecting and enhancing the natural environment.

FHWA has published a series of three Final Rules which, together, establish a set of performance measures for State departments of transportation (State DOT) and Metropolitan Planning Organizations (MPO) to use as required by MAP-21 and the FAST Act. The performance measures relating to traffic operations are contained in the third Final Rule, which was published in the Federal Register on January 18, 2017. The Final Rule was originally scheduled to be effective February 17, 2017, but the effective date was postponed until May 20, 2017 in accordance with a memorandum from the Assistant to the President and

Chief of Staff issued January 20, 2017 entitled “Regulatory Freeze Pending Review.” The Greenhouse Gas (GHG) measure was postponed indefinitely by publication in the Federal Register on May 19, 2017. On October 5, 2017, the FHWA issued a Notice of Proposed Rulemaking which would permanently repeal the GHG measure.

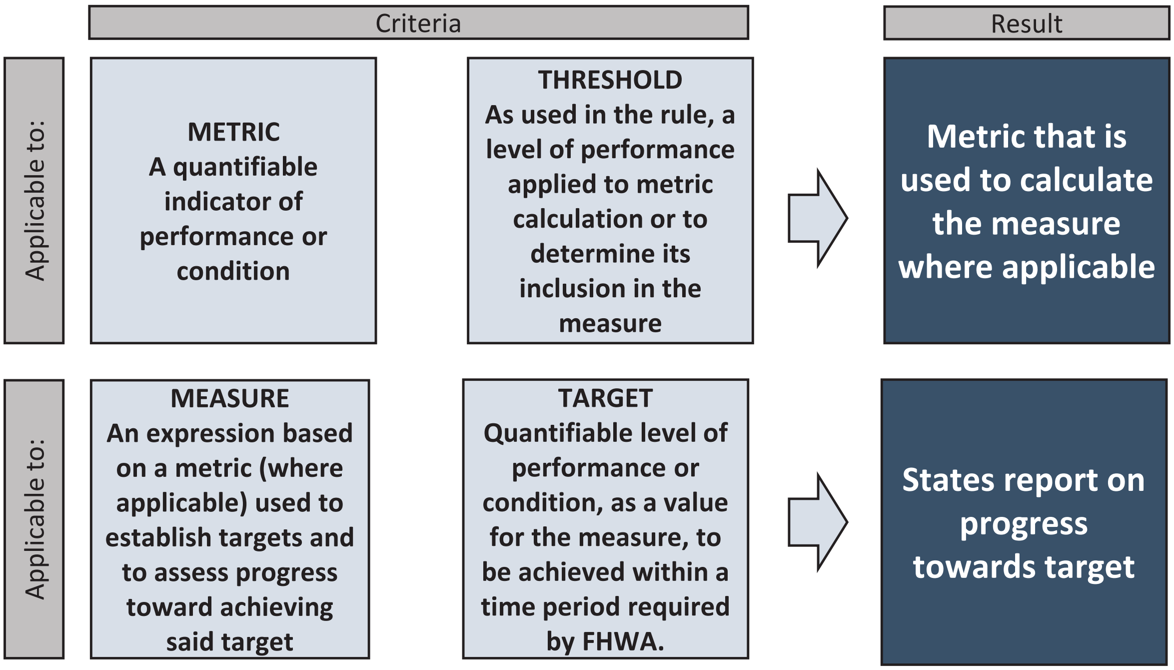
A draft of the requirements was published as a Notice of Proposed Rulemaking (NPRM) in the Federal Register on April 22, 2016, and the comment period closed on August 20, 2016. PennDOT provided 13 pages of comments, which was coordinated by the PennDOT Center for Program Development and Management.

The regulations for Transportation Performance Measurement are contained in 23 CFR Part 490. In addition to general requirements in Subpart A, the subparts relating to traffic operations to be calculated by HSTO which are addressed via the third Final Rule are as follows, along with the performance measures defined in each Subpart:

- Subpart E: Measures to Assess Performance of the National Highway System (NHS)
    - Interstate Travel Time Reliability measure - §490.507(a)(1) (percent of person-miles traveled on the Interstate that are reliable)
    - Non-Interstate Travel Time Reliability measure - §490.507(a)(2) (percent of person-miles traveled on the non-Interstate NHS that are reliable)
- Subpart F: Measures to Assess Freight Movement on the Interstate System
    - Freight Reliability measure - §490.607 (Truck Travel Time Reliability (TTTR))
- Subpart G: Measure for Assessing the CMAQ Program – Traffic Congestion
    - PHED measure - §490.707(a) (Annual Hours of Peak Hour Excessive Delay (PHED))

Each of the criteria has both metrics and measures. Metrics are used to indicate whether performance meets a threshold, and the measure is typically an aggregation of the system which meets the metric threshold. Ultimately, states are responsible for meeting the targets for the measure, although the metrics may also have value for agencies in understanding what drives the measure and in identifying actions which have affected the measure. The interrelationship between metrics, thresholds, measures, and targets are shown in Figure 20.

FIGURE 20: FEDERAL PERFORMANCE MEASUREMENT FRAMEWORK



Source: FHWA

A summary of the metrics, measures, and applicability is shown in Table 14.

TABLE 14: FHWA PERFORMANCE MEASURES SUMMARY

Performance Area	Measure	Metric	Coverage			Geography			Targets	
			Interstate NHS	Non-Interstate NHS	National Highway System (NHS)	State	MPO	Urbanized Areas[2]	2-Year	4-Year
System Performance	Percent of Person Miles Traveled	Travel Time Reliability (LOTTR)	X	X		X	X		X[3]	X
System Performance	GHG Emissions[1]	Tailpipe CO^2 emissions (GHG)			X	X	X		X	X
Freight	Index	Travel Time Reliability (TTTR)	X			X	X		X	X
Congestion	Annual Hours Per Capita	Peak Hour Excessive Delay (PHED)			X			X	X[3]	X

[1]Proposed for repeal
[2]Urbanized Areas greater than 1 million population (greater than 200,000 starting in 2022) that overlay AQ areas
[3]2-year targets are not required for the first performance period for non-interstate NHS LOTTR and PHED measures

Targets

State DOTs and MPOs are required to establish targets for each of the performance measures. Targets apply to the transportation network or geographic area, regardless of ownership, including bridges that cross State borders. Two-year targets are to be established reflecting the midpoint of the performance period, and 4-year targets reflecting the end of each performance period. The 4-year target can be adjusted at the mid-point of the target period.

PennDOT is responsible for establishing a statewide target for the reliability measures. Baseline measures are provided for each MPO to understand the regional variations driving the statewide values. Since the software used to calculate the measures doesn't provide for PennDOT District level calculations, Districts are encouraged to review data for the applicable MPOs to gauge their progress.

MPOs may either agree to support the statewide targets by programming projects designed to help achieve the statewide targets, or they may develop their own targets. PennDOT Districts should work with their planning partners to consider how candidate projects for the LRTP and TIP will achieve the federal performance targets.

State DOTs are required to achieve or make significant progress toward their targets every biennial reporting period (every 2 years), and are to take additional reporting actions if FHWA determines significant progress is not made. Significant progress means that either the actual performance is better than the baseline performance or that the target is achieved, even if the performance degraded. Significant progress is required for the following traffic operation/congestion measures per §490.109(a):

- Interstate Travel Time Reliability measure
- Non-Interstate Travel Time Reliability measure
- Freight Reliability measure

Significant progress will not be determined for the other measures in the Final Rule.

For the Interstate Travel Time Reliability and Non-Interstate Travel Time Reliability, if FHWA finds significant progress is not made for any of the targets, then the State DOT shall document the actions it will take to achieve NHS travel time targets or the GHG measure target, as applicable. For the Freight Reliability measure, there are more significant requirements to be incorporated into the next performance target report under 23 U.S.C. 150(e) [the Biennial Performance Report]. The State DOT is required to update the Biennial Performance Report within 6 months of being notified by FHWA that significant progress is not made to document and ensure actions are being taken to achieve targets.

The third Final Rule notes FHWA does not have authority under MAP-21 to approve or reject State DOT or MPO established targets. Although the regulations don't suggest how targets should be set, FHWA indicates targets can be constant, increasing, or declining. While State DOTs and MPOs have flexibility in defining the targets, the targets may only be adjusted or revised at the times indicated in the regulations.

Timeline

The regulations include timelines for establishment of performance targets by State DOTs and MPOs as well as reporting requirements. Due to the length of time to complete the regulatory process, FHWA phased the timeline so the traffic operations requirements in the third Final Rule will take effect after the requirements in the first two Final Rules. However, the goal is to eventually align the reporting periods.

Performance Targets

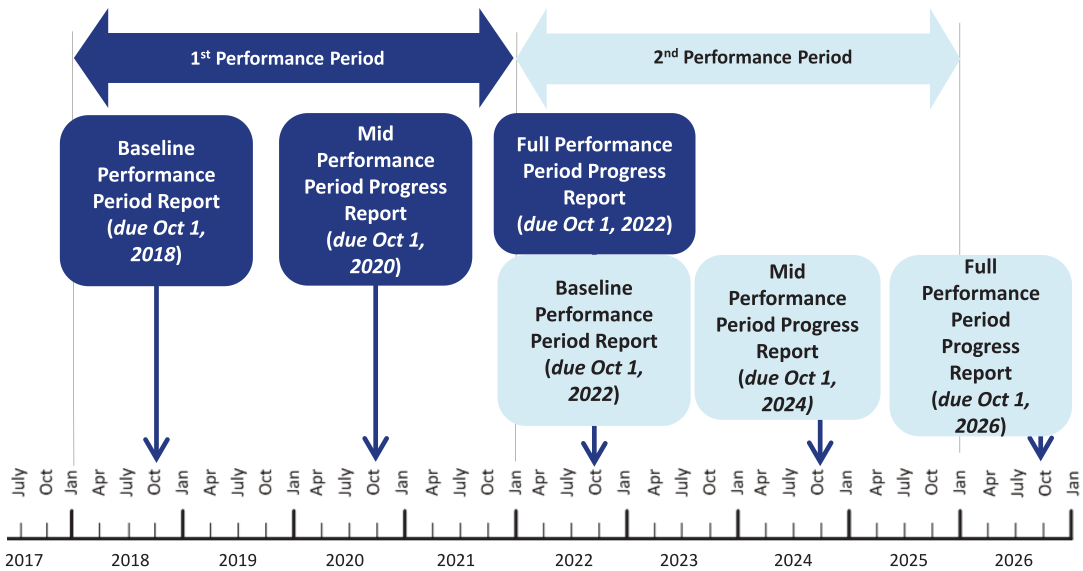
The initial performance targets shall be submitted by the State DOTs to FHWA by May 20, 2018. The performance targets for subsequent performance periods shall be submitted with enough time to meet all regulatory requirements.

MPOs shall agree to program projects supporting the statewide target or establish their own targets within 180 days after the State DOT establishes targets or modifies targets.

Reporting

The performance period extends for four years, with the first performance period beginning January 1, 2018. Statewide reporting completed by PennDOT will occur at an on-going 2-year frequency, representing performance through the midpoint and conclusion of each performance period with the reports due to FHWA the following October 1. Reports consist of a Baseline Performance Period Report (BPPR), Mid Performance Period Progress Report (MPPPR), and Full Performance Period Progress Report (FPPPR), as shown in Figure 21.

FIGURE 21: FHWA TIMELINE FOR BIENNIAL PERFORMANCE REPORTING



Source: FHWA

For the first performance period, the Non-Interstate Travel Time Reliability Measures is being phased in, with different reporting requirements. The baseline condition/performance will be determined in the MPPPR using the 2-year condition/performance. Therefore, a 2-year target will not be set in the BPPR for the first performance period.

Reporting of performance at the regional level will occur within each MPO's LRTP.

The requirements for each performance report are summarized in Table 15. In addition to the report measuring progress toward the targets, State DOTs are required to report several metrics in other manners, as indicated in Table 16.

TABLE 15: FHWA PERFORMANCE MEASURE REPORTING REQUIREMENTS

Content	BPPR	MPPPR	FPPPR
Condition/performance	Baseline	2-Year	4-Year
Targets for the performance period	Establish 2-year and 4-year targets and discuss basis	2-year progress achieving targets with discussion of differences; summary of prior accomplishments and planned activities; discussion of extenuating circumstances adjusted 4-year target, if applicable	4-year progress achieving targets; discussion of differences; summary of accomplishments during the performance period to demonstrate whether significant progress made toward achievement of 4-year target; discussion of extenuating circumstances
Investment strategies		Discuss effectiveness	Discuss effectiveness
Other performance expectations	Discuss relationship between targets support other documented expectations, such as long-range plans		
Urbanized areas	Document boundaries		
Freight bottlenecks	Identify locations from State Freight Plan	Discuss progress addressing congestion at truck freight bottlenecks	Discuss progress addressing congestion at truck freight bottlenecks
Nonattainment and maintenance area	Document boundaries	N/A	
MPO CMAQ Performance Plan	Include as attachment	Include as attachment	Include as attachment
Percent of Non-SOV Travel measure	Establish data collection methodology	N/A	N/A
Actions from prior report	N/A	Description of actions to better achieve targets, if not met from prior performance period	Description of actions to better achieve targets if 2-year target not met in MPPPR

TABLE 16: FHWA PERFORMANCE MEASURE DATA SUBMISSION REQUIREMENTS

Metric	Precision	Method	Reporting Frequency	First Due	Reporting Granularity
LOTTR[1]	Nearest 0.01	HPMS	Annually, June 15th	June 15, 2018	NPMRDS TMC or HPMS section
80th percentile travel time[1]	Nearest second	HPMS	Annually, June 15th	June 15, 2018	NPMRDS TMC or HPMS section
Normal (50th percentile) travel time[1]	Nearest second	HPMS	Annually, June 15th	June 15, 2018	NPMRDS TMC or HPMS section
Directional AADT		HPMS	Annually, June 15th	June 15, 2018	NPMRDS TMC or HPMS section
TTTR[2]	Nearest 0.01	HPMS	Annually, June 15th	June 15, 2018	NPMRDS TMC or HPMS section
95th percentile truck travel time[2] Nearest	second	HPMS	Annually, June 15th	June 15, 2018	NPMRDS TMC or HPMS section
Normal (50th percentile) truck travel time[2]	Nearest second	HPMS	Annually, June 15th	June 15, 2018	NPMRDS TMC or HPMS section
PHED	Nearest 0.01 hr	HPMS	Annually, June 15th	June 15, 2018	NPMRDS TMC or HPMS section

[1]For the following time periods:
Weekdays (Monday-Friday): 6:00 a.m. to 10:00 a.m., 10:00 a.m. to 4:00 p.m., and 4:00 p.m. to 8:00 p.m.
Weekends (Saturday-Sunday): 6:00 a.m. to 8:00 p.m.

[2]For the following time periods:
Weekdays (Monday-Friday): 6:00 a.m. to 10:00 a.m., 10:00 a.m. to 4:00 p.m., and 4:00 p.m. to 8:00 p.m.
Weekends (Saturday-Sunday): 6:00 a.m. to 8:00 p.m.
All days (Sunday-Saturday): 8:00 p.m. to 6:00 a.m.

Travel Time Data Source

FHWA is requiring the performance measures involving travel time to be calculated using either the National Performance Management Research Data Set (NPMRDS) or an equivalent data set. NPMRDS must be used unless the State DOT requests, and FHWA approves, the use of an equivalent data source(s) that meets the requirements of §490.103(e). FHWA is promoting the use of NPMRDS for national consistency with the reported results. If an equivalent data source is approved, the same data set must be used for all travel time derived metrics, and MPOs and the State DOT must use the same data set. Specific requirements of the data set include:

- Average travel times in 15-minute bins, recorded to the nearest second, for the following time periods:
    - All traffic on each segment of the NHS
        - 24 hours on Interstates
        - 6 a.m. to 8 p.m. on non-Interstate NHS
    - Freight vehicle traffic on each segment of the Interstate System (24 hours)
- Breakdown of travel times between freight vehicles and all traffic (including both freight and passenger vehicles)
- Travel times cover contiguous segments of roadway for the entire NHS mainline highways
- Travel must be observed and may be derived from travel times over longer time periods (known as path processing or equivalent) (no imputed methods)
- Be available within 60 days of measurement

Of specific note is the requirement that the data set must be populated with observed vehicle travel times and shall not be populated with travel times derived from imputed methods (historic travel times or other estimates); i.e. travel time must be observed. PennDOT has invested in INRIX data, which uses historic data to provide estimates where actual data is unavailable. INRIX is the data provider for the new NPMRDS contract which takes effect July 1, 2017. Although the underlying data source is the same, the segmentation is different (NPMRDS uses TMC segments, INRIX provides XD segments to PennDOT) and the format of the INRIX data made available through the NPMRDS contract is compliant with the MAP-21 travel time data source requirements. Therefore, it is recommended that the NPMRDS version of INRIX data be used for the MAP-21 performance measures.

The PDA Suite includes the ability to calculate MAP-21 performance measures in the Final Rule using the NPMRDS data.

Reporting Segments

A single-set of reporting segments shall be defined and be used consistently between the State DOT and MPOs, which shall be based on the following:

- Shall be comprised of one or more contiguous Travel Time Segments of the same travel direction
- Shall not exceed 1 mile in length in urbanized areas and 10 miles in length in non-urbanized areas unless an individual Travel Time Segment is longer
- All reporting segments collectively shall be contiguous and cover the full extent of the directional mainline highways of the Interstate System and non-Interstate NHS required for reporting the measure.

The NPMRDS Travel Time Segments may be used as reporting segments and the creation of new reporting segments is not required.

State DOTs shall submit the defined reporting segments and the desired travel times to FHWA no later than November 1st prior to the beginning of a calendar year in which they will be used for travel time data collection.

It is noted the Travel Time Segments in NPMRDS do not align with segments in PennDOT's Roadway Management System (RMS).

Performance of the National Highway System (Subpart E)

Two performance measures are used to assess the National Highway System (NHS):

- Percent of person-miles traveled on the Interstate system that are reliable (Level of Travel Time Reliability – LOTTR)
- Percent of person-miles traveled on the non-Interstate NHS that are reliable (Level of Travel Time Reliability – LOTTR)

Travel Time Reliability (LOTTR)

Metric: Level of Travel Time Reliability (LOTTR) for each of the following time periods for each reporting segment:

- Weekdays (Monday-Friday)
  - 6:00 A.M. – 10:00 A.M.
  - 10:00 A.M. – 4:00 P.M.
  - 4:00 P.M. – 8:00 P.M.
- Weekends (Saturday-Sunday)
  - 6:00 A.M. – 8:00 P.M.

LOTTR is defined as the ratio of the 80th percentile travel time to the normal (50th percentile) travel time (example calculations in Figure 22). The percentile travel times are determined from a data set containing January 1st through December 31st of each year in 15 minute intervals for each of the four time periods.

FIGURE 22: EXAMPLE LOTTR CALCULATIONS

$$\frac{\text{Longer Travel Time (80th)}}{\text{Normal Travel Time (50th)}} = \frac{\text{\# seconds}}{\text{\# seconds}} = \text{Level of Travel Time Reliability Ratio}$$

Level of Travel Time Reliability (LOTTR) *(Single Segment, Interstate Highway System)*		
Monday – Friday	6am – 10am	$\text{LOTTR} = \frac{44 \text{ sec}}{35 \text{ sec}} = 1.26$
	10am – 4pm	LOTTR = 1.39
	4pm – 8pm	LOTTR = 1.54
Weekends	6am – 8pm	LOTTR = 1.31
Must exhibit LOTTR below 1.50 during **all** of the time periods		**Segment IS NOT reliable**

Source: FHWA

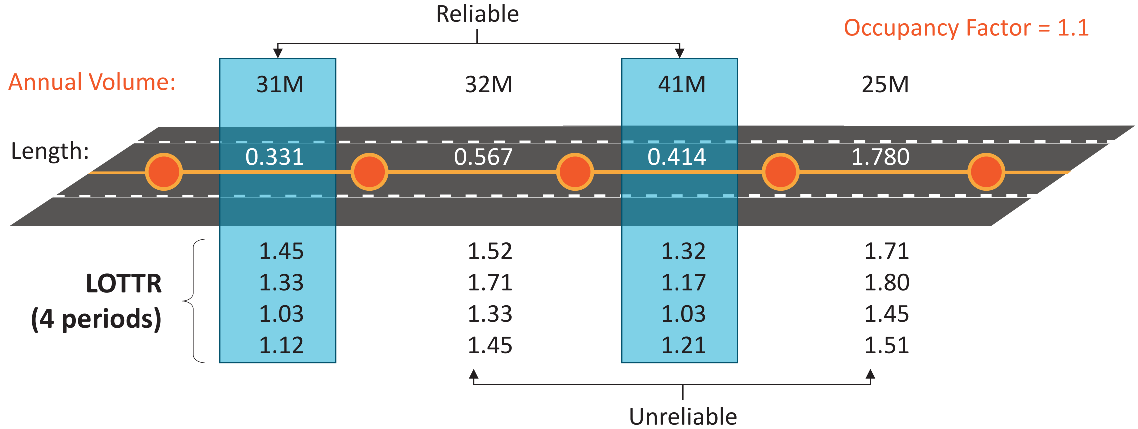
Threshold: A reporting segment is considered reliable if LOTTR < 1.50 for all of the four time periods.

FHWA recognizes there may be time periods (15 minute bins) where there were no vehicle probes, resulting in blank data. For this metric, missing travel times shall not be replaced. Time periods when an NHS roadway is closed may be excluded from the calculations.

Measure: Percent of person-miles reliable, for full extent of the system (Interstate and Non-Interstate NHS)

The percent is calculated by dividing the sum of reliable person-miles by the sum of total person-miles. Person-miles for each total are calculated by adding the product of segment length (to nearest 0.001 mile), total annual volume of the segment (AADT x 365), and the average vehicle occupancy factor. Figure 23 provides an example of this calculation.

FIGURE 23: EXAMPLE TRAVEL TIME RELIABILITY MEASURE CALCULATION



$$\text{Travel Time Reliability Measure} = \frac{(0.331 \times 31 \times 1.1) + (0.414 \times 41 \times 1.1)}{(0.331 \times 31 \times 1.1) + (0.567 \times 32 \times 1.1) + (0.414 \times 41 \times 1.1) + (1.780 \times 25 \times 1.1)}$$

$$= \frac{11.287 + 18.671}{11.287 + 19{,}958 + 18.671 + 48.950}$$

$$= \frac{29.958}{98.866}$$

$$= 30.3\%$$

Source: FHWA

The average occupancy factors for the State and/or metropolitan area (as applicable) needed to calculate the Travel Time Reliability measures shall come from the most recently available data tables published by FHWA unless using other allowed data source(s).

Freight Movement on the Interstate System (Subpart F)

One performance measure assesses freight movement, which only applies to the Interstate System:

- Truck Travel Time Reliability (TTTR) Index

Truck Travel Time Reliability

Metric: Truck Travel Time Reliability Index (TTTR) for each reporting segment, for each of the following six time periods:

- Weekdays (Monday-Friday)
  - 6:00 A.M. – 10:00 A.M.
  - 10:00 A.M. – 4:00 P.M.
  - 4:00 P.M. – 8:00 P.M.

- Weekends (Saturday-Sunday)
  - 6:00 A.M. – 8:00 P.M.

- Every day (Sunday-Saturday)
  - 8:00 P.M. – 6:00 A.M.

TTTR is defined as the ratio of the 95th percentile truck travel time to the 50th percentile truck travel time (example calculation in Figure 24). The percentile travel times are determined from a data set containing January 1st through December 31st of each year in 15 minute intervals for each of the four time periods.

FIGURE 24: EXAMPLE TTTR CALCULATIONS

$$\frac{\text{Longer Truck Travel Time (95th)}}{\text{Normal Truck Travel Time (50th)}} = \frac{\text{\# seconds}}{\text{\# seconds}} = \text{TTTR Ratio}$$

TTTR: Single Segment, Interstate Highway System		
Monday – Friday	6 – 10 a.m.	TTTR = $\frac{63\text{ sec}}{42\text{ sec}}$ = 1.50
	10 a.m. – 4 p.m.	TTTR = $\frac{62\text{sec}}{45\text{sec}}$ = 1.38
	4 – 8 p.m.	TTTR = $\frac{85\text{ sec}}{50\text{ sec}}$ = **1.70**
Weekends	6 a.m. – 8 p.m.	TTTR = $\frac{52\text{ sec}}{40\text{ sec}}$ = 1.30
Overnight	8 p.m. – 6 a.m.	TTTR = $\frac{52\text{ sec}}{40\text{ sec}}$ = 1.21
Maximum TTTR		**1.70**

Source: FHWA

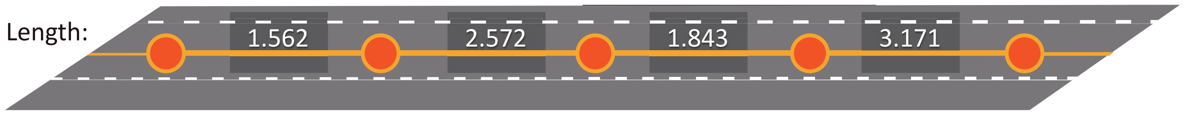
FHWA recognizes there may be time periods (15 minute bins) where there were no freight vehicle probes, resulting in blank data. For this metric, the Final Rule requires the all-traffic travel time be substituted for the freight vehicle travel time. Time periods when an NHS roadway is closed may be excluded from the calculations.

Threshold: There is no threshold for this metric.

Measure: Truck Travel Time Reliability (TTTR) Index, for the full extent of the Interstate system

The overall TTTR Index measure is determined by the highest TTTR ratio of the five time periods for a particular roadway segment, aggregated and weighted by segment length, as shown in Figure 25.

FIGURE 25: EXAMPLE FREIGHT RELIABILITY MEASURE CALCULATIONS



TTTR	1.50	**2.10**	1.45	1.56
	1.38	1.83	**1.71**	**2.30**
	1.70	1.79	1.62	2.12
	1.30	1.42	1.22	1.82
	1.21	1.03	1.01	1.27

$$\text{TTTR} = \frac{(1.70 \times 1.562) + (2.10 \times 2.572) + (1.71 \times 1.843) + (2.30 \times 3.171)}{(1.562 + 2.572 + 1.843 + 3.171)}$$

$$= \frac{2.655 + 5.401 + 3.152 + 7.293}{9.148}$$

$$= 2.022$$

Source: FHWA

Measures for Assessing the CMAQ Program – Traffic Congestion (Subpart G)

Traffic congestion, as part of the CMAQ Program, is assessed with the following performance measures:

- Annual Hours of Peak Hour Excessive Delay (PHED) Per Capita (Total Peak Hour Excessive Delay, person-hours)
- Percent of Non-SOV Travel

The Percent of Non-SOV Travel measure is calculated through PennDOT's Center for Program Development and Management, and is not described further in this chapter.

The CMAQ performance measures are applicable to all urbanized areas that are designated as nonattainment or maintenance areas for ozone, carbon monoxide or particulate matter National Ambient Air Quality Standards (NAAQS) that include NHS mileage and have:

- A population over 1 million for the first performance period (2018-2022)
- A population over 200,000 for the second and all other performance periods (2023-beyond)

The following urbanized areas apply for the first performance period:

- Philadelphia
- Pittsburgh

The following additional urbanized areas will apply for the second performance period and beyond:

- Allentown
- Harrisburg
- Lancaster
- Reading
- York

The following urbanized areas have a population greater than 200,000 but do not have any nonattainment areas:

- Youngstown, OH
- Scranton

The Erie urbanized area was just under 200,000 population from the 2010 Census, but may have reached the population threshold based on updated estimates since the last decennial Census. The Erie urbanized area does not contain any non-attainment areas.

Peak Hour Excessive Delay

Metric: Total excessive delay (person-hours) for each reporting segment on the NHS

Peak period excessive delay is calculated only during the following weekday time periods:

- 6:00 A.M. – 10:00 A.M.
- Either 3:00 P.M. – 7:00 P.M. or 4:00 P.M. – 8:00 P.M. (State DOTs and MPOs may choose which 4-hour block to use)

Calculation of this metric requires hourly volumes for each reporting segment. The Final Rule indicates states may use either of the following methods to measure or estimate hourly traffic volumes:

- Use hourly traffic volume counts collected by continuous count stations and apply them to multiple reporting segments
- Use Average Annual Daily Traffic (AADT) reported to HPMS to estimate hourly volumes. AADT data must use most recently available data, which can be no more than 2 years older than the reporting period.

The hourly volume methodology shall be reported to FHWA no later than 60 days before the submittal of the first Baseline Performance Period Report (August 2, 2018).

First, the Excessive Delay Threshold Travel Time is calculated as the travel time through the reporting segment at the threshold speed (20 mph or 60% of the speed limit, whichever is greater). Then the Excessive Delay is calculated as the difference between the actual travel time and the excessive delay threshold travel time for each 15 minute bin of each reporting segment. The Total Excessive Delay is aggregated over the year by multiplying the traffic volume by the delay in each 15 minute bin.

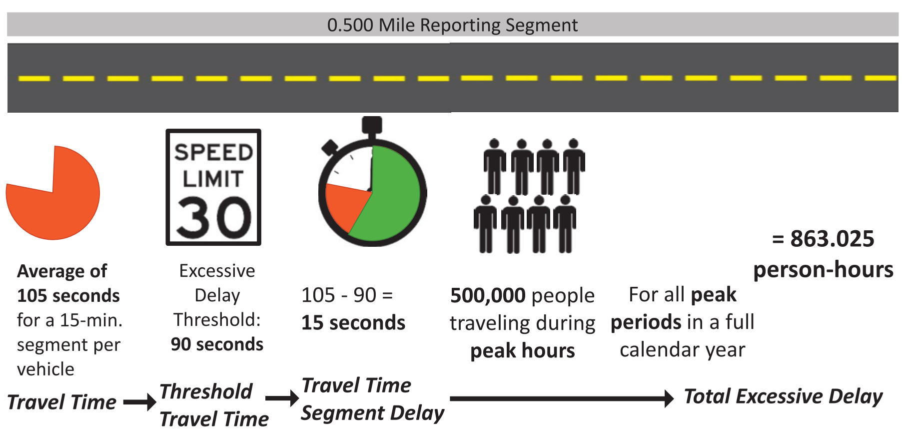
Conversion of PHED to person-hours requires both vehicle classification and annual average vehicle occupancy data, with the average vehicle occupancy data being a weighted average of cars, buses and trucks for each roadway segment. Figure 26 provides an example of this conversion to person-hours. Vehicle classification is the percentage of cars, buses and trucks, relative to the total AADT for each segment, using one of the following methodologies:

- Use annual volume counts collected by continuous count stations to estimate
- Use AADT reported to HPMS with buses as HPMS Data item "AADT_Single_Unit," trucks as "AADT_Combination" and cars as the remainder of vehicles in the AADT.

Annual average vehicle occupancy (AVO) factors are required for cars, buses, and trucks, using one of the following methodologies:

Use estimated annual average vehicle occupancy factors provided by FHWA

FIGURE 26: EXAMPLE CONVERSION TO PERSON-HOURS



Source: FHWA

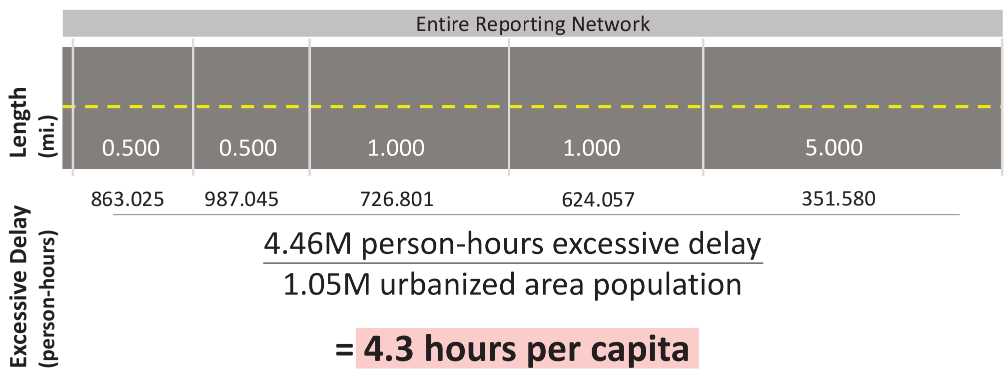
Use an alternative estimate of annual average vehicle occupancy factors, provided that it is more specific than the data provided by FHWA

Threshold: Travel Time at 20 mph or at 60% of the posted speed limit for each segment, whichever is greater

Measure: Peak hour excessive delay per capita

The total excessive peak hour delay is aggregated for the urbanized area(s) and divided by the urbanized area population to determine the total annual hours of peak hour excessive delay per capita. Figure 27 provides an example of these calculations.

FIGURE 27: EXAMPLE EXCESSIVE DELAY PER CAPITA CALCULATIONS



Source: FHWA

Planning for Implementation

The FHWA measures will most likely not serve all the needs of PennDOT's traffic operations performance measure program. The FHWA measures provide a snapshot of system-level performance including the times and locations of congestion, but these measures don't go into the depth necessary to identify the cause of congestion in order to make traffic operational decisions and take actions necessary to move the needle on the FHWA measures. Therefore, the Department will still have a need to develop performance measures above and beyond the FHWA measures. Since RITIS has been developing methods to calculate the FHWA measures, the simplest solution may be to use RITIS for MAP-21 compliance and continue developing a separate performance measures program to meet the Department's traffic operational needs.

It appears there are some data sets which will need to be conflated with the NPMRDS data set in order to calculate some measures, such as traffic volumes. Although TTI has completed some of this under the new NPMRDS contract, initial data validation by PennDOT has indicated there are conflation issues with using HPMS data. PennDOT is working to develop a new conflation process to provide more accurate traffic volumes to RITIS for calculation of the measures, as well as providing speed limit data which is required for the PHED measure.

Setting the targets will be a critical part of the process to ensure significant progress is made toward achieving the targets. Therefore, it is recommended as many previous years as possible for the measures be calculated using the NPMRDS data set in order to determine an appropriate baseline as well as the expected fluctuation in the measures. The targets should be set in a manner which would allow typical fluctuations in performance without causing a penalty for the state or MPOs.