# Assessing and Reporting on Traffic Management System (TMS) Capabilities and Performance—Current Practices

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## FOREWORD

Traffic management systems (TMS) and traffic management centers are critical resources that offer agencies the potential to improve the safety and mobility of travel on the surface transportation system. TMSs also assist agencies in fulfilling the ever-increasing transportation needs of travelers (e.g., travel times), service providers (e.g., transit, emergency services), other agencies, and the public (e.g., incidents). Agencies continue to be challenged with improving the performance of their TMSs, expanding the geographical service area, expanding or enhancing services, and providing funding and staffing needed to manage, operate and maintain the systems.

This report outlines the technical and other considerations (e.g., processes, information technology, staffing) needed for executing a transition between versions of a TMS or specific subsystems (e.g., software, computing hardware). The practices and methods captured in this report can assist agencies when they plan, design, procure, develop, implement, test, operate, and evaluate improvements to TMSs. This report may be of interest to representatives from State departments of transportation, local agencies, metropolitan planning organizations, regional authorities, toll authorities, and other groups engaged in transitioning from a current TMS to a new version, replacing a subsystem of a TMS, or adding new subsystems or capabilities to an existing TMS.

Carl Andersen
Acting Director, Office of Safety and
Operations Research and Development

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16. Abstract

This report aids public agencies in planning and assessing their traffic management system (TMS) to gain insight into their capabilities, performance, and potential areas for enhancements. The report provides information about opportunities to integrate existing TMS capabilities, performance, resources needed for improvements, and resources needed to support TMS management and operations into the agency or region's programs, planning processes, or plans. The report discusses the benefits of conducting a TMS assessment, as well as the processes and considerations involved in preparing, conducting, and identifying possible improvement opportunities based on the assessment results. The report identifies the issues to consider during an assessment, whom to consider involving in the process, and what to consider when preparing for and facilitating the assessment. Additionally, the report highlights potential stakeholders to include in the TMS assessment process, explains how to summarize the results and identify possible improvements, and provides guidance on incorporating these results into the agency's or region's planning processes, programs, or plans.


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## SI* (MODERN METRIC) CONVERSION FACTORS

### APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yard | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| | **NOTE**: volumes greater than 1,000 L shall be shown in $m^3$ | | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2,000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| °F | Fahrenheit | 5 (F-32)/9<br>or (F-32)/1.8 | Celsius | °C |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | $cd/m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| $lbf/in^2$ | poundforce per square inch | 6.89 | kilopascals | kPa |

### APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.314 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2,000 lb) | T |
| | | **TEMPERATURE (exact degrees)** | | |
| °C | Celsius | 1.8C+32 | Fahrenheit | °F |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| $cd/m^2$ | candela/m2 | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 2.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | $lbf/in^2$ |

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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| | |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| API | application programming interface |
| ATDM | active transportation and demand management |
| ATM | active traffic management |
| Caltrans | California Department of Transportation |
| CCTV | closed-circuit television |
| CMF | Capability Maturity Framework |
| CMM | Capability Maturity Model |
| DMS | dynamic message signs |
| DOT | department of transportation |
| FDOT | Florida DOT |
| FHWA | Federal Highway Administration |
| GDOT | Georgia Department of Transportation |
| HAR | highway advisory radio |
| HSIP | Highway Safety Improvement Program |
| IoT | Internet of Things |
| IP | Internet Protocol |
| IT | information technology |
| ITS | intelligent transportation systems |
| KPI | key performance indicator |
| KSA | knowledge, skills, and abilities |
| MDOT | Michigan DOT |
| MnDOT | Minnesota DOT |
| MOU | memorandum of understanding |
| MPO | metropolitan planning organization |
| NJDOT | New Jersey DOT |
| ODOT | Ohio DOT |
| PennDOT | Pennsylvania DOT |
| RWIS | road weather information system |
| TAMP | transportation asset management program |
| TIM | traffic incident management |
| TMC | traffic management center |
| TMS | traffic management system |
| TOAST | Traffic Operation Assessment Systems Tool |
| TRANSCOM | Transportation Operations Coordinating Committee |
| TSMO | transportation systems management and operations |
| VDOT | Virginia DOT |

# CHAPTER 1. INTRODUCTION

As State and local agencies look for ways to safely improve the mobility of the traveling public, those agencies continue to design and implement traffic management systems (TMSs) to help achieve these goals. TMSs are a complex, integrated blend of hardware, software, processes, and people performing a range of functions and actions. TMSs combine field equipment, operations personnel, and advanced communications and information technology (IT) to meet their missions. TMSs enable human operators to perform functions, actions, and services that support improving the safety, efficiency, and predictability of travel on the surface transportation network.

As agencies consider opportunities to improve the capabilities, performance, and planning, or explore improving a TMS, those agencies face a number of challenges. These challenges may include active management and operation improvements, the utilization of emerging data sources, the integration of new technologies, and the costs associated with expanding system coverage, enhancing services, and managing, operating, or maintaining a TMS. Before planning or pursuing improvement projects, agencies may benefit from first assessing the capabilities and performance of their current TMS.

An assessment of a TMS may provide information and insight on current capabilities, performance, resource needs, and potential areas for enhancements. The results of a TMS assessment provide information to support agencies considering immediate changes, exploring improvement options, and planning for the future evolution of their system. Information obtained from an assessment can be used throughout the lifecycle of a TMS to enhance its performance, management, and operation.

Leveraging existing planning efforts and plans is important when planning for or assessing the aspects of a TMS that may need improvement to meet the needs of an agency, region, or any specific geographical area. Many agencies do not conduct feasibility studies for a TMS, and many may not have multiyear transportation management strategic plans to lay the groundwork on which to build TMS plans. Agencies may consider developing and integrating plans for TMS into existing agency planning efforts, especially transportation systems management and operations (TSMO) plans, or intelligent transportation systems (ITS) strategic plans.[1,2]

This document outlines current and emerging practices for agencies to consider when assessing the TMS capabilities, performance, and resources available to manage, operate, and sustain the system. It addresses the potential issues to consider when preparing for, conducting, and summarizing the results of an assessment of the current capabilities and performance of a TMS. The objectives of this report are as follows:

- Present the types of information used in assessing TMS capabilities and performance.
- Discuss methods to conduct the assessment.
- Identify and overcome issues in preparing for and conducting TMS assessments.

- Present options to use the results of TMS assessments to prepare actions plans for improvements.

- Identify opportunities to link the results from TMS assessments to other agency programs, processes, and plans.

This document includes the following key information:

- Issues to consider when assessing TMS—This document presents the types of issues an agency may confront when performing TMS assessments. Issues may include lacking experience or information available to consider or assess current capabilities or performance, strategically planning for future improvements or resource needs, planning for future improvements to upgrading TMSs, or preparing to transition to the next-generation of an agency's TMS.

- Preparing for a TMS assessment—This document summarizes overall preparation for a TMS assessment and covers key aspects such as issues to consider, inputs, outputs, related processes, and determining whether a related assessment has been conducted. Additionally, this document provides information to consider from an agency's programs, policies, procedures, services, strategic plans, and plans.

- Conducting a TMS assessment—This document discusses conducting TMS assessments, including the benefits of the assessment, the processes to be used, what components and factors to assess, and how to prepare for the assessment. It includes a list of dimensions, while also explaining the need for additional dimensions beyond those previously identified by the Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA).[3] These additional dimensions aim to align with the lifecycle of a TMS and its key phases, such as repairs and maintenance.

- Using the TMS assessment results and action planning—This document covers the potential of using the results of a TMS assessment in various programs, processes, and planning efforts. References to how the results of a TMS assessment may be used in planning efforts (e.g., TSMO plan development), funding requests, transportation planning processes, and planning for or developing improvement projects are included.

This report contains information gathered from various sources, including interviews with city, county, and State departments of transportation (DOTs) as well as metropolitan planning organizations (MPOs) stakeholders. Additionally, this report incorporates and builds on information collected from published literature and the current resources developed by AASHTO and FHWA to support a Capability Maturity Model (CMM).[3] This report also uses the available TSMO program resources published by FHWA.[4]

## ASSESSING AND REPORTING ON TMSS

This section provides an overview of TMSs and their purpose, including what TMSs are designed for and enabled to perform (e.g., functions, services, actions). This section also explains what is meant by assessing and reporting on the TMSs capabilities and performance. Chapters 2

and 3 provide more detail on conducting TMS assessments, understanding the lifecycle of a TMS, introducing the eight dimensions of a TMS assessment, and exploring the range of issues to consider when preparing for and conducting a TMS assessment.

**Value Proposition**

A common statement when referring to systems that help monitor, manage, and improve performance is: What is not measured cannot be managed. TMSs perform functions, services, and actions that support improving the efficiency, safety, and predictability of travel on the surface transportation network. Effective management of TMS assets may not be achieved until an agency is first able to measure and report on the performance of their TMS and portions of the surface transportation system the TMS is managing.

Capabilities can be described as what a TMS can do. An example is a TMS centralized traffic signal control system. In this instance, a TMS that possesses such a centralized system can (at least theoretically) manage and control the operation of all the connected signal devices from a central location, enabling the TMS to manage its network of traffic signals as a unified whole, versus a collection of individual devices. The ability to deliver and then maintain this centralized control are considered capabilities. The following items are benefits of assessing TMSs' capabilities:

- Summarize current capabilities: Summarization allows for a comprehensive big-picture view of the capacity of the overall TMS to support effective system operation. Summarization also allows for the appropriate prioritization of needs.

- Evaluate performance and document benefits: This analysis supports possible improvements or changes in how the agency manages and operates a TMS to yield the desired outcomes. These results have the potential to positively influence several agency programs, in addition to improving the performance of the facilities being managed.

- Build support with key partners and stakeholders included in assessment: The value of TMS assets goes beyond just the agency that owns and maintains them. Nurturing support for ongoing investment in and support for procurement, operations, and maintenance of the TMS and its different assets is important.

- Provide a basis for comparing future capabilities and performance: With a baseline established, an agency can programmatically identify and prioritize possible future improvements (e.g., add or enhance functions or operational strategies).

- Identify areas and opportunities for future improvements: Agencies may continually examine investment alternatives to assess whether newer, enhanced assets are preferable to maintaining existing assets.

- Support development of action plans to improve capabilities: After reviewing and establishing baselines for the capabilities of the different TMS dimensions, as well as examining areas of future enhancements, this information provides agencies an opportunity to identify future improvements or changes to how the TMS is managed and operated.[3,5]

- Enhance planning, programming, and decisions to allocate resources (e.g., funding and staffing): Ultimately, an assessment of current TMS capabilities and performance provides the basis to consider future TMS improvements in other agency or regional programs, planning efforts, and plans.

Performance as it pertains to a TMS describes how well a TMS can do what a TMS is intended to do. Agencies can refer to the previous example of a centralized traffic signal control system and use different measures to assess the capabilities and performance of the system and the functions, services, or actions the system may perform.

The value in assessing a TMS lies in the assessment's ability to provide an understanding of the system's capabilities and performance. Agencies may gain valuable insights into various aspects of their TMSs by assessing the systems' capabilities and performance, ultimately leading to improved operations and better resource management. This information may also enable more informed decisionmaking involving allocating resources for improvements or enhancements to TMS management and operation. In this context, agencies should consider the following items when assessing the capabilities and performance of TMSs:

- System effectiveness: An assessment of the degree to which the TMS and its assets achieve the desired operational outcomes.

- System reliability: The degree to which the TMS is functioning when called on to do so.

- Management and operation of the TMS: An evaluation of whether the performance of the TMS can be improved by enhancing processes, procedures, or support systems.

- Implications of operational decisionmaking: The analysis of whether the TMS assets enable effective decisionmaking in an operational environment.

- Condition of TMS assets: Asset condition assessment, conducted based either on the assets' functional state or the phase of the asset lifecycle, whichever basis is useful for defining whether an asset needs maintenance, upgrades, or replacement.

Assessing TMS capabilities and performance also provides a foundation for informed decisionmaking in follow-on efforts by providing the following information to support agencies:

- Evaluating options to improve TMS performance: If the TMS or its assets are not meeting performance targets, the agency can examine whether upgrades, configuration changes, or replacement can bring the TMS to acceptable performance levels.

- Exploring implications of changing the way a TMS is managed and operated: These changes can be as simple as configuration changes, operational setting modifications, changes to decisionmaking approaches, or revising thresholds.

- Optimizing the allocation of resources and asset management, such as operations, maintenance, and repair.

- Conducting planning efforts to identify and prioritize needed improvements.

## INTENDED AUDIENCE

The intended audience of this report includes representatives from State DOTs, local agencies, MPOs, regional authorities, toll authorities, and other groups that support TMSs. Consultants, contractors, and researchers who work with TMSs or support agencies that operate TMSs may also benefit from this report. The audience includes traffic management center (TMC) managers, supervisors, transportation engineers and planners, operators, maintenance personnel, IT staff, the research community, and others with a role in the TMS lifecycle.

An individual's specific role and responsibilities within a TMSs lifecycle may influence how a reader uses this report because certain chapters or sections may be more relevant than others. For example, managers just starting the asset inventory process or looking for examples of what information to document as part of an inventory may find the chapters on inventory and documenting assets important. Maintenance personnel may place higher importance on the inventory and documentation information, while the research community may want a higher level understanding of the processes.

## REPORT ORGANIZATION

This report identifies current and emerging practices to assess and report on TMSs' capabilities and performance. This report leverages findings from a review of published literature, such as industry publications, association websites, government websites, workshop materials, journals, and reports. Appendix B provides the literature referenced while preparing this report. The report also includes information gathered during one-on-one interviews with select agency personnel.

This report includes six chapters and is organized as follows:

- Chapter 1. Introduction: Introduces the purposes and objectives of the report, background on TMS asset assessment and reporting, the value proposition for this effort, and who may benefit from reading the document.

- Chapter 2. Assessing TMSs: Provides an overview of the topics covered in this report and demonstrates how information captured from assessing a TMS could support other agency or regional processes and plans. This chapter describes a TMS and then explains the key issues and processes to consider when preparing for, conducting, and using the results of a TMS assessment.

- Chapter 3. TMS Capabilities and Performance: Provides information on the range of issues to consider when assessing TMS capabilities and performance, a broad overview of TMS program structure, and how performance measures can be included in the TMS assessment. This chapter introduces performance monitoring and reporting.

- Chapter 4. Conducting an Assessment: Discusses the assessment process, a range of issues and information to consider, and who to consider including in the process. This chapter also explores the issues an agency may want to consider when preparing to conduct an assessment, summarizes the results of the assessment, and explores what to consider, including an action plan to improve the TMS.

- Chapter 5. Assessment Dimensions: Discusses how the eight dimensions of a TMS Capability Maturity Framework (CMF) may be used to assess TMSs.[6] This chapter also examines how agencies could use the CMF to gauge the capabilities, performance, and overall maturity of the TMS.

- Chapter 6. Assessment of TMS Capabilities: Provides information about the issues to consider and the lessons learned from current practice for assessing TMS capability and performance that were gathered in preparing this report.

- Appendix A. Example Reports and Dashboards.

- Appendix B. Literature Reviewed for this Project.

# CHAPTER 2. ASSESSING TMSS

## OVERVIEW

This chapter presents an overview of the range of issues agencies may want to consider in the context of assessing the capabilities and performance of a TMS, describes TMSs, and explores the steps and issues to consider when preparing for, conducting, and summarizing the results of a TMS assessment. This information provides the reader with the dimensions to review, the range of issues to consider, and a basis for identifying the capabilities and performance of a TMS.

This chapter includes the following specific objectives:

- Identify the TMS lifecycle and the methods agencies use to plan, design, develop, enhance, or replace their TMSs.
- Introduce the eight dimensions of a CMF to support assessing TMSs.
- Identify the issues agencies may want to consider when assessing the performance and capabilities of their TMSs.
- Introduce methods that an agency may use to summarize the results of a TMS assessment and then use that information to prepare an action plan for future enhancements, pursue planning efforts to develop TMS improvements, or explore changes in how a TMS is managed and operated.

This chapter includes the following sections:

- TMSs: Provides a definition and a history of TMSs and describes the role of a TMS within an agency's TSMO program.
- TMS Assessment: Introduces the concept of assessing a TMS's capabilities and performance and using the results of a TMS assessment in other processes in the TMS's lifecycle.
- TMS Lifecycle: Introduces the processes, plans, and activities conducted in the typical lifecycle of a TMS.
- Motivations for Assessing TMSs: Explores the possible short-term and long-term agency motivations for assessing their TMS.
- TMS Assessment Dimensions: Introduces the issues and factors to consider in the eight dimensions of a TMS assessment CMF.

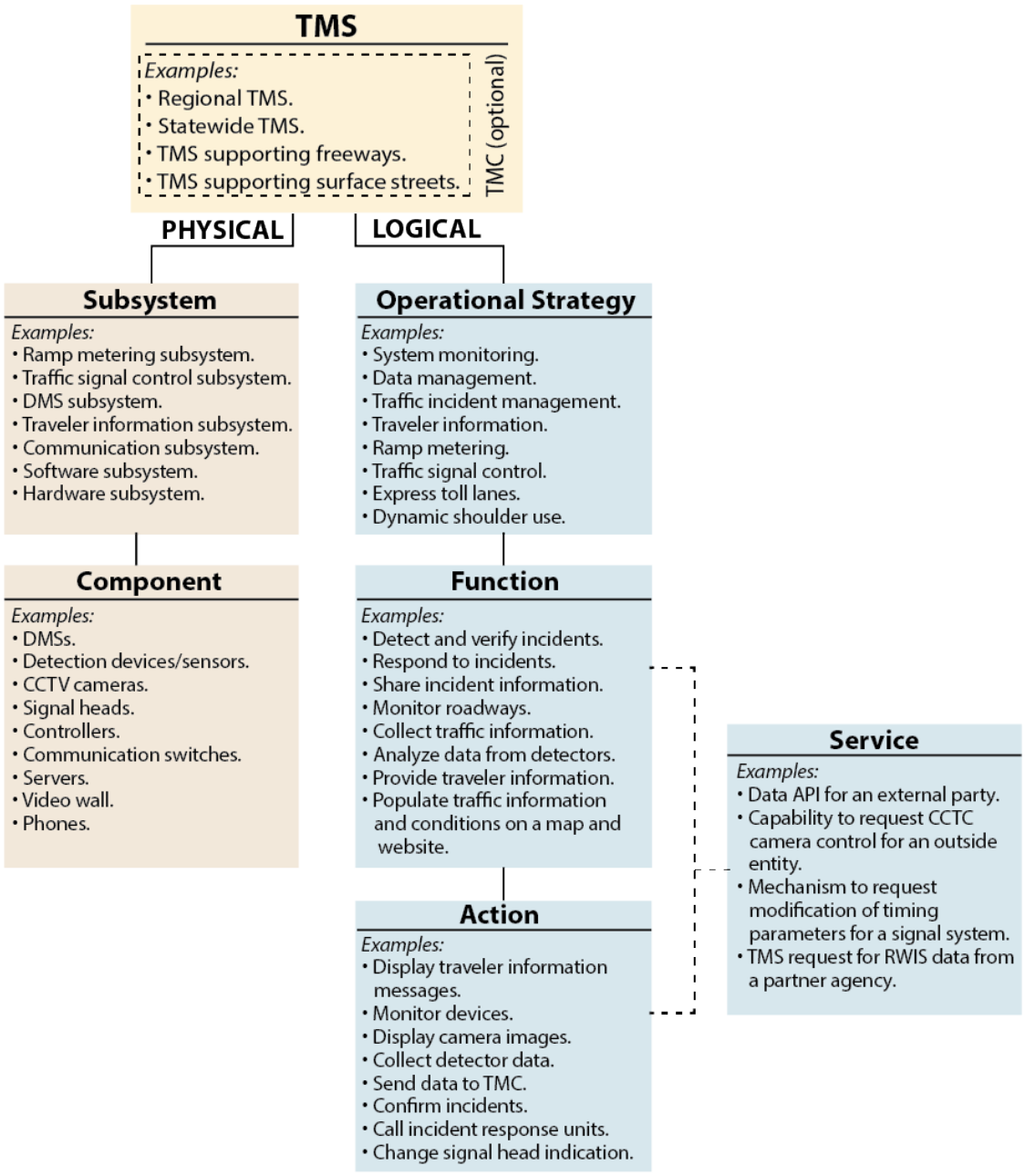
**TMSs**

Agencies aim to balance physical roadway capacity limitations, budget constraints, safety and operational enhancement needs, and sustainable transportation operations solutions implementation as a means of good stewardship. Therefore, many agencies have adopted TSMO programs to leverage operational strategies to achieve this balance.

Agencies have recognized the importance of incorporating management and operations in their mission statement to continuously enhance their transportation network's performance and reliability. The seamless integration of TMSs into various operational strategies is key to the successful management and operations of the transportation network.

TMSs are complex systems combining field equipment, communications equipment, IT, and software tools. TMSs support agency staff are actively managing and operating a range of functions and actions to facilitate improvements in the efficiency, safety, and reliability of travel on the surface transportation system.

The design or structure of a TMS can be divided into its physical elements and its logical elements. The physical elements include the subsystem and the components. The logical elements include the operational strategies, functions, actions, and services. Figure 1 represents the TMS structure.




Source: FHWA.
DMS = dynamic message signs; CCTV = closed-circuit television; API = application programming interface; RWIS = road weather information system.

**Figure 1. Diagram. TMS structure.[7]**

A TMS is composed of multiple subsystems, physical components, and logical components. Each TMS component is managed and operated daily. Additionally, agencies provide ongoing maintenance and repairs for individual physical components as needed to provide those components' intended level of performance. Example physical TMS components are individual ITS devices (such as changeable message signs), closed-circuit television (CCTV) cameras, traffic signal heads, controllers, servers, or video walls. On their own, individual physical TMS

components provide little value to an agency's goals. As part of an integrated system, these devices, components, and subsystems work together to support agencies managing and controlling traffic to improve mobility and safety.

A TMS provides an agency with the ability to perform operational strategies by leveraging the connected physical subsystems and components. These strategies include traffic incident management (TIM), traveler information, traffic signal control, and part-time shoulder use.

A TMS also provides a platform for agency staff to execute the following logical functions:

- Monitoring roadways.
- Collecting traffic and incident information.
- Populating traffic information.
- Analyzing detector data.
- Responding to traffic incidents.
- Populating traffic information on a map or website.

In addition to strategies and functions, a TMS is also composed of individual actions. These actions, as the lowest level logical element, most closely match daily TMS operations and management. Example actions include monitoring an individual device, sending data to the TMC, confirming individual traffic incidents, or updating the display of a lane use control sign.

Through knowledge of existing TMS subsystems and understanding of how those subsystems are used to fulfill operational strategies, agencies can capture their current system's performance, assess and document TMS functions, and explore options to improve performance or plan for the next generation of TMS. From an assessment point of view, an agency needs to prepare to document the structure of the TMS to identify information the agency needs to collect for the assessment.

Inventory of existing operational strategies and assembly of documentation on those strategies' operational implementations can also provide the initial information for the assessment. This inventory and assembly includes understanding what documentation is available and what data are being collected to document the operational performance of each of the listed strategies. Listing the strategies the agency wants to consider for the future is another consideration. Understanding future strategies' importance to and impact on the TMS can provide insight about components that are missing or need improvements.

**TMS Assessment**

This section reviews the history of the CMM and introduces the concept of assessing a TMS, creating an action plan, and using the results of an assessment to plan for TMS improvements.[(4)] It also explains how the TMS assessment relates to other processes an agency may support in the TMSs lifecycle. This section also relates a TMS assessment to other existing resources that may be used for assessing a TSMO program or specific elements of the program or operational strategies.

The Second Strategic Highway Research Program found that agency TSMO programs are most effective when the agency has strong institutional, operational, and technical capabilities.[8] Based on this finding, the CMM was adopted.[4] The CMM framework provides agencies with a set of questions that assess their current level of performance across various dimensions.[9] FHWA has used the CMM to develop CMFs for specific areas such as traffic management, incident management, and road weather management.[10] These tailored CMFs help agencies and stakeholders focus on identifying opportunities to improve specific capabilities in a particular operational area.

The CMFs offer a method for consistently recognizing the challenges and opportunities within each TSMO program area.[4] By using a CMF for a self-evaluation, agencies can arrive at a mutual agreement on what improvements are necessary to prioritize the implementation of those improvements. The CMFs ultimately provide agencies with a roadmap for advancing their TSMO program activities so the agencies can manage and operate their surface transportation system. However, no specific CMF is currently available for assessing an agency's TMS capabilities, performance, or how the system is integrated into the agencies TSMO program, other agency or regional programs, and plans.

To fill this gap, this report draws on existing TSMO CMFs, such as the traffic management CMF, to support its development.[4] Chapter 5 proposes slight modifications to the existing CMM frameworks to better align with the issues unique to TMSs. An agency may use the results of a TMS assessment to develop an action plan that outlines specific needs for improving TMS capabilities. The action plan may include recommendations for changes in TMS management and operations, policies and procedures, or for pursuing planning efforts or projects to improve TMS capabilities. Once created, the action plan may also be used in conjunction with other efforts to advance an agency's TSMO program activities. Figure 2 illustrates how a TMS self-assessment fits into all agency planning processes and efforts that may impact the management and operation of a TMS. The next section provides more details on the typical processes, plans, and activities that may occur in the lifecycle of a TMS.


Source: FHWA.

**Figure 2. Illustration. TMS planning process.**

## TMS Lifecycle

A TMS assessment is a key process in the lifecycle of a TMS, as it provides a structured framework to review and evaluate the current capabilities and performance of the system and how that system is being managed and operated. This information may also be used to establish a baseline to consider in planning efforts to identify the desired future capabilities and performance of the TMS. This information is valuable when agencies plan for upgrades, replacements, or enhancements to their current TMS. The TMS itself has its own lifecycle, as do individual components and subsystems.

Upgrades to individual TMS components and subsystems are also necessary to keep pace with changing needs, current condition of assets, and required services (e.g., maintenance, repairs, replacements). For example, an agency may upgrade its CCTV cameras to provide new video analytics functionality or upgrade an entire subsystem by introducing a new active transportation and demand management (ATDM) strategy. Such upgrades may involve enhancing software features or changing TMC staffing, telecommunication, and field components. These improvements may need to be considered and incorporated into a TSMO program plan, TMS program plan, or resource management plan to support the operation, management, and maintenance of TMS components and assets.

To successfully manage a project for the procurement of a new or improved TMS, agencies must first understand the impact of these changes. Establishing performance measures and targets for

the TMS can assist with managing the successful development and implementation of these changes. When planning for TSMO projects, traffic operations initiatives, or other enhancements, key considerations are the potential impacts of these changes on the TMS's functionality, services, resources, capabilities, and operations, and the agency's ability to implement and maintain the TSMO projects.

When updating long-range transportation plans, agencies might consider the overall impact on TMS components and assets. State and regional agencies also develop other long-term transportation plans, which could be expanded to incorporate TMS improvements and the resources to support or enhance the management and operations of TMSs. At the agency and regional levels, these multiyear strategic plans typically cover a range of long-term and short-term improvement projects, initiatives, or activities that may influence the environment in which agencies manage and operate TMSs. Such planning efforts and supporting plans can include TMS enhancement plans, feasibility studies, efforts to prioritize or select TMS projects, and other planning activities such as corridor studies, transportation improvement programs, and congestions management plans.

Figure 2 depicts different processes in the lifecycle of a TMS, along with opportunities for the results of these processes to serve as inputs into other planning processes and plans within an agency or region:

- TMS self-assessment.
- Preparing and developing strategic TMS plans.
- TMS planning and feasibility studies.
- TMS programming, resource allocation, and operation and maintenance.
- TMS procurement, project development, and implementation.
- TMS monitoring, evaluation, and reporting.
- TMS maintenance and repairs.

**Motivations for Assessing TMSs**

This section discusses the motivation for an agency to conduct an assessment on TMSs and the benefits of assessing TMSs. By conducting an assessment, an agency gains a better understanding of the TMS's current operations and performance, including how each subsystem, component, action, function, service, and strategy works together to achieve operational goals. This understanding can lead to opportunities for performance improvement and enhanced capabilities, such as making small changes to individual elements of the TMS, or optimizing current technologies, data, strategies, or resources. The assessment can also reveal opportunities to improve the management and operation of the TMS or allocate resources to support the maintenance of individual elements. By reviewing the overall system performance, agencies can ensure that they make the most of their limited resources.

Another motivation for a TMS assessment is to establish a baseline of the capabilities, support structure, integrations, and resources involved. This baseline supports the agency's ability to improve various TSMO program areas such as ATDM or TIM. Understanding how all TMS elements currently work together can enable future planning or process improvement efforts.

Agreement on the baseline of TMS capabilities, elements, and resources impacting functionality helps agencies prioritize goals and opportunities for future enhancements.

Assessing a TMS also has implications for an agency's TSMO program. The TMS is a key component of many TSMO program areas, including ATDM and TIM. By assessing the TMS, agencies can identify opportunities to improve these program areas and enhance the overall efficiency and effectiveness of the TSMO program. For example, by improving the TMS's incident detection and response capabilities, agencies can reduce incident duration, coordinate with stakeholders to respond to and clean incidents, and improve traffic flow, which can lead to improved safety and reduced congestion.

Conducting a TMS assessment also helps agencies identify all current and future demands on the TMS. As new technologies and data-sharing agreements are introduced, agencies may need to adapt to changing conditions to ensure that the TMS can meet evolving demands. By engaging key stakeholders and understanding current and future demands on the TMS and resources, agencies can better prioritize opportunities for improvement and establish goals for future TMS capabilities and performance. Additionally, agencies can better understand the challenges to adopting future TMS changes. Developing a consensus around needed improvements and how these improvements should be prioritized increases the clarity of future resource demands.

After assessing current resources, the information may be used in other agency or regional processes to identify and establish a consensus around possible future TMS improvements. The consideration of current capabilities and performance in these processes offer agencies an opportunity to estimate future resource needs, such as financial, staffing, policy, and technology. Agencies can fill existing gaps in system performance in the short term or prioritize for future enhancements.

Agreed-upon priorities for enhancing future TMS capabilities and performance measures that support assessing these enhancements can be incorporated into agency plans. Occasionally, an agency may decide to pursue a new or next-generation TMS instead of making incremental improvements to their existing system. A system assessment and agreed-upon priorities for future improvements can serve as a baseline when planning and considering possible improvements to or capabilities needed for the next generation of an agency's TMS.

Finally, an agency could incorporate the findings and outcomes of a TMS assessment into other transportation planning processes and plans, such as TSMO program plans, safety improvement plans, or long-range transportation plans. By continuously reassessing and adapting to changing conditions, agencies can identify actions to continuously improve TMS capabilities and performance, ensuring the TMS can meet evolving demands.

The following circumstances can serve as a catalyst for an agency's decision to assess their TMSs capabilities and performance:

- The agency is developing or updating a TMS program or TMS plan.
- The agency is developing or updating their TSMO program or TSMO plan.

- The agency is making significant TSMO investments.
- The agency is reviewing or updating the resource needs, resources, or program and plan to support its TMS.
- The agency or TSMO program is being reorganized.
- The agency wants to reevaluate its TMS's capability and performance to determine if its TMS capability has improved based on the action plans implemented.

If an agency has previously performed an initial assessment, some of these circumstances may motivate the agency to reexamine the results of its previous assessment or revisit the capability tool.[11] The agency can also perform an assessment to evaluate the results of action plan implementation, initiatives, or other changes to managing and operating a TMS. By conducting regular assessments and reporting on the capabilities of their TMSs, agencies can ensure sustained resources and support within the organization. This ongoing process allows for continuous improvement in understanding who should participate, what information may be needed, and how to conduct and approve the results of the assessment.

**TMS Assessment Dimensions**

This section discusses the TSMO CMM and individual CMFs, as well as the opportunity for a TMS-specific CMF.[4,6] This section also introduces the eight dimensions for conducting a TMS assessment, issues to consider for each dimension, potential sources of data and information to support the assessment, and example differences between capability levels for each dimension. Chapter 5 provides a more detailed discussion of the TMS assessment dimensions.

As mentioned in a previous section, some of the existing CMFs can be currently used to conduct a quasi-assessment of a TMS.[11] The traffic management assessment is the most applicable framework. The systems and technology dimension of the traffic management CMF helps agencies conduct a narrow self-assessment of their TMSs. More indepth information is needed for a full assessment of TMS capabilities and performance. As with existing CMFs, the six core dimensions should be considered for a TMS assessment. However, the TMS is a core part of real-time operations being used in an ongoing fashion. As such, the TMS assessment introduces two new dimensions: management and operations and maintenance and repair.

Combined with the other dimensions, the following eight dimensions are recommended for a TMS assessment:[6]

- Business process.
- Systems and technology.
- Performance measurement.
- Culture.
- Organization and workforce.
- Collaboration.
- Management and operations.
- Maintenance and repair.

The eight dimensions are introduced in this section. Chapter 5 provides a more detailed discussion for each TMS assessment dimension.

### *Business Processes*

The business process dimension focuses on an agency's planning, programming, budgeting, project development processes, and other agency efforts that may involve TMS resources, contracts, or priorities.[3] To ensure an agency's TMS operates effectively and continues to grow, several key factors must be considered, such as the availability of staff to manage and operate the system, funding to improve TMS capabilities, and long-term planning efforts to enhance TMS capabilities.

Business processes consider the broad institutional support required for an agency's TMS. The effectiveness and growth of a TMS can either be supported or hindered by procurement processes, staffing contracts, management activities, and internal knowledge of these processes. Therefore, examining these processes and ensuring the processes align with the agency's TMS goals and objectives to enable the TMS to operate effectively is important.

When assessing business processes maturity level, the agency should consider the following questions:[3]

- Does the agency have a TMS maintenance or enhancement plan?
- Does the agency TSMO plan prioritize TMS maintenance or enhancements?
- Are TMS capabilities tied to specific regional transportation challenges?
- Does the agency have established performance measures for the TMS?

When differentiating possible levels of maturity, the agency should consider the sustainability of the funding and staffing assigned to TMS operations.[3] Is the funding dedicated each fiscal year? Do key performance indicators (KPIs) exist for the performance of agency staff or contracted personnel? Are TMS plans and enhancements and workflows being implemented and institutionalized?

### *Systems and Technology*

The systems and technology dimension focuses on issues that may include the planning for future improvements, the existence of a strategic multiyear plan to inform future evolution of the system, TMS needs and proposed future improvements integrated into other agency or regional plans, condition of assets, systems standards, and interoperability of agency TMS elements. This dimension is concerned with designing and implementing processes, plans, initiatives, or actions to meet the agency's needs and available resources, and to encourage interoperability between systems, subsystems, components, and devices. The goal is to ensure that the agency's systems are well designed and implemented in a manner that facilitates effective operation, supports the management of their evolution, and ensures the availability of necessary resources for effective management and operation.

As it relates to a TMS assessment, this dimension needs broadening to encompass the consideration of the technologies and the functions, services, and actions supported by the TMS.

Agencies may consider evaluating whether the existing technologies and capabilities will meet the agency's future needs as new technologies are being adopted. If agencies deem changes to these capabilities necessary, an assessment of the underlying technologies becomes pertinent to ensure the TMS continues to effectively support the desired functions, services, and actions.

Consider the following issues when assessing how the systems, their capabilities, and their supporting technologies impact TMSs:

- Are the agency's TMS software, hardware, data, communication, and field devices able to meet current and future TMS demands?
- What type of communications does the agency use for the TMS?
- Does all TMS field equipment fit into the TMS and regional ITS architectures?[(2)]
- How easy is it to integrate new data feeds or applications with the agency TMS?

When differentiating levels of maturity, the agency should consider how the agency manages all TMS hardware, software, field devices, and communications capabilities.[(3)] Are all components integrated into one system? How seamlessly can new technologies be integrated into the TMS? Is the systems engineering process followed for the integration of newer components?

***Performance Measurement***

The performance measurement dimension focuses on using performance measures to determine program effectiveness, inform future decisionmaking, and demonstrate the extent of transportation problems to substantiate prioritizing future operations initiatives.[(3)] For a TMS, performance measures can include the indirect impact on roadway mobility as well as technical performance of the TMS itself.

TMS performance measures include the following parameters:

- TMS impact on mobility performance measures (e.g., congestion), safety, and reliability.
- Usability and user acceptance of the TMS.
- Technical performance of the TMS itself.
- The maturity of the TMS data management and reporting capabilities.
- TMS capabilities to provide insights for specific traffic management strategies.

Consider the following issues when assessing performance measurements' impact on TMS capabilities:

- Does the agency TMS have the capability to measure overall system performance?
- Has the agency developed a performance measurement system and is this information used for routine TSMO program management and reporting efforts?
- How does the agency manage or process performance data?
- How many TMS-generated performance measures are tied to strategic agency goals?

When differentiating levels of maturity, the agency should consider the thoroughness and usability of TMS performance measures.[3] Does the TMS enable a comparison of current conditions to historical system performance? Does the TMS-generated information encourage or complicate decisionmaking? Do system performance metrics inform real-time operational decisions?

***Workforce and Organization***

The workforce and organization dimension considers staffing and other resources supporting TMS operations, enhancements, and maintenance.[3] This dimension focuses on program management, how staff is recruited, structured, developed, and retained. The workforce, as it relates to TMS operations, refers to operational staff, maintenance staff, and planning and engineering staff.

Staffing and staff development can be common issues for TMS operations. As new technologies and strategies are developed, TMS personnel will need specific new knowledge, skills, and abilities (KSAs). Agencies may need to develop new roles or expand existing roles to consider the development and management of the TMS.

Consider the following issues when assessing workforce and organization impact on TMS capabilities:

- Do key agency positions supporting the TMS have formal succession plans?
- Are TMS operations and maintenance supported by staff 24 h a day, 7 d a week, and 365 d a year?
- Are the agency's human resources policies and procedures flexible enough to recruit and retain agency staff with the needed skill sets?
- Are all TMS personnel under one common management with clearly defined performance goals?

When differentiating levels of maturity, the agency should consider the skill sets needed to maintain TMS performance.[3] Are staff empowered to suggest improvements to the TMS management and operations? Does the agency have internal training programs to retain TMS

capabilities and technical knowledge? How often are the organizational structure and staffing levels evaluated based on TMS effectiveness?

### *Culture*

The culture dimension considers an agency's overall expectations of and value placed on TMS capabilities and performance. The culture dimension includes how comfortable the agency is with innovation and workforce pride. Some agencies have a culture encouraging innovation. For these agencies, efforts to increase TMS capabilities are often encouraged and supported across the agency. Other agencies may resist adopting new technologies to avoid further impact on limited agency resources. For these agencies, the culture may impede the ability to grow TMS capabilities and performance.

Culture also considers how well existing staff cooperate and how much each staff member feels a connection to impacting meaningful performance measures. In some cases, a workforce may feel a sense of pride and togetherness. In other cases, rifts may exist between different work groups.

Consider the following issues when assessing the culture impact on TMS capabilities:

- How many agency divisions have awareness of or integrations with the TMS?
- Do agency staff working with the agency TMS have pride in their work and feel as if they are performing important work?

When differentiating levels of maturity, the agency should consider whether well-defined workforce performance metrics exist, and how often these metrics are shared.[3] Is each work unit aware of their ability to make decisions and directly impact TMS KPIs? Does the agency as a whole understand the TMSs impact on mobility and safety? Are other agency divisions, outside of the typical operations or TSMO group, using TMS-generated information for their programs or communications efforts?

### *Collaboration*

The collaboration dimension considers partnerships with other public agencies, first responders, or private partners. This dimension highlights the importance of relationships between other transportation agencies, public safety agencies, and the private sector. Different forms of collaboration can make a TMS more effective and mature.

Collaboration can take place between systems and between people. These relationships can encourage cross-jurisdictional traffic management solutions and increase coordination of similar efforts (e.g., work zone lane closure coordination). System-to-system collaboration highlights the ability of a TMS to integrate with other systems and data sources. People-to-people collaboration highlights the ability of individuals within the same organization to share information and coordinate their efforts.

Consider the following issues when assessing the collaboration impact on TMS capabilities:

- Does the TMS support cross-jurisdictional activities?
- Does the TMS consume data from, or share data with, partners?
- Are there any existing memorandums of understanding (MOUs) between partner agencies?
- What existing private public partnerships related to TMS functionality exist?

When differentiating different levels of maturity, the agency should consider agreed-upon regional objectives and coordination.[3] Have agency partnerships been formalized? Are roles and responsibilities clearly identified between partners? Are the TMS program plan or proposed future improvements included in the agency's TSMO Program and Plan, the agency's strategic plans, or regional plans?

### *Management and Operations*

The management and operations dimension considers the day-to-day support of TMS functions and daily use of TMS strategies. Agencies continuously manage and operate their TMSs. Many TMSs are operated 24 h a day, 7 d a week. Different approaches may be taken to manage and operate TMS resources. In most cases, TMC staff are responsible for the primary TMS operations. During normal business hours, the TMC staff may have management available to support TMS operations. Outside of normal business hours the TMC may become more self-sufficient in handling TMS operations (e.g., TIM). The management and support structure can either hinder or support TMS operations. A few issues to consider when assessing the management and operations impact on TMS capabilities include:

- How much redundancy exists among agency staff responsible for operating the TMS?
- How flexible is the agency's approach to TMS management and operations?
- How empowered are workgroups to make decisions in realtime?
- Does the agency have a continuity of operations plan for emergencies impacting TMS operations?

When differentiating levels of maturity, the agency should consider existing support structure and service-level agreements.[3] How quickly can TMS support staff respond to immediate needs? How well-documented are approval processes? How are new procedures communicated to the workforce?

### *Maintenance and Repair*

The maintenance and repair dimension considers ongoing support of TMS functionality and enhancements, as well as condition monitoring and upgrading of individual TMS elements. TMS failures cause significant impact to travel performance, safety, and reliability. Agencies

incorporate maintenance into the planning and design of a TMS program by specifying how the TMS will be monitored, how the agency will plan for and react to system malfunctions, and the resources required to maintain the TMS. Also tied into maintenance and repair is the system durability and dependability. A TMS, as well as individual TMS components, is ideally always available almost 100 percent of the time. Even during routine updates, not taking TMS functionality offline during upgrades is preferrable.

Consider the following issues when assessing the maintenance and repair impact on TMS capabilities:

- How dependable is the TMS?
- How easy is it to maintain the TMS and TMS components?
- Are TMS elements maintained in a prioritized method?
- Does the agency maintenance management system and software include TMS assets?

When differentiating levels of maturity, the agency should consider the agency's TMS maintenance structure as well as the TMS's historical performance.[3]

## CAPABILITY LEVELS

Table 1 summarizes the four levels of capability maturity the CMF uses to assess the current state of maturity and identify improvement targets for each program area.[3] These capability levels are applied to each dimension listed in the previous sections. Chapter 5 further discusses the maturity levels and how the maturity levels are reflected in the range of organizational capabilities.

**Table 1. Traits of agencies at different levels of capability maturity.[3]**

| Maturity Level[3] | Description |
|---|---|
| Level 1: Developing | Activities and processes are largely ad hoc, informal, and champion-driven, and substantially outside the mainstream of other DOT activities. |
| Level 2: Established | Basic strategy applications understood, key processes support identified requirements, and key technology and core capacities under development but limited internal accountability and uneven alignment with external partners. |
| Level 3: Measured | Standardized strategy applications implemented in priority contexts and managed for performance; TSMO technical and business processes developed, documented, and integrated into DOT; partnerships aligned. |
| Level 4: Managed | Full sustainable core DOT program priority, established based on continuous improvement with top-level management status and formal partnerships. |

## APPLYING THE CAPABILITY MATURITY FRAMEWORK

Using the CMF is a collaborative effort often conducted as part of an assessment.[3] The assessment of the capabilities may involve discussions among peers and members of different groups within TMS. The assessments and assignments of capabilities can be somewhat subjective even though over time and after repeated process, the group support assessments may become more consistent with evaluating and determining the levels of capabilities for each dimension.[3] The assessments themselves do not carry significant meaning except in the context of an organization that seeks to improve itself, compare changes in capabilities and performance over time, and concentrate on potential adjustments in the allocation of its limited resources in a few specific areas. The assessment helps to frame the discussion around identifying areas where the organization excels and where stakeholders think more effort and focus may be needed.

Applying the CMF typically involves the following four steps:[5]

- Step 1—Assemble a group of stakeholders to conduct a self-assessment; agree on the issues to consider in the assessment; conduct the assessment, and work through a process of consensus to agree on and record the results of the assessment.

- Step 2—Identify the capability level based on the assessment.

- Step 3—Present a list of possible actions to address gaps identified or improvements identified to capabilities and performance for each dimension. Select the highest priority actions for possible implementation: planning, project development, or management and operational changes.

- Step 4—Create a summary of the assessment with an action plan, which may include the agreed-upon list of actions for the stakeholders to consider.

Chapter 4 discusses each of the steps in greater details and provides context and practical considerations on how to conduct the assessment.

# CHAPTER 3. TRAFFIC MANAGEMENT SYSTEM CAPABILITIES AND PERFORMANCE

The previous chapter provided an overview of TMS assessment and its supporting activities. It connected the assessment to other agency processes, explained the steps involved in preparing for, conducting, and utilizing the results of the assessment. The purpose was to give the reader a foundational understanding of these concepts and to establish a basis for detailed discussions in this chapter.

This chapter delves into TMS programs, TMS capabilities and performance, and trends affecting TMSs. The objective is to provide an overview of TMS program structure and how performance measures can be included in the TMS assessment.

This chapter has the following goals:

- Discuss the scope and purpose of the TMS program.
- Introduce TMS performance monitoring and reporting.
- Highlight examples of performance measures.
- Discuss trends and issues affecting TMS.

The chapter consists of the following sections:

- Traffic Management System Program: Discusses TMS program as an integrated approach for managing various aspects of TMS as standalone or as part of TSMO program.

- Traffic Management System Performance: Focuses on performance measures and reporting and how those performance measures can be included in an assessment.

- Trends and Issues to Consider: Covers current technological and organizational advancements impacting TMS.

Material covered in this chapter will help the reader to appreciate various aspects of TMS, which can be evaluated in the assessment process. The actual assessment process will be covered in the next chapter.

## TRAFFIC MANAGEMENT SYSTEM PROGRAM

To ensure accountability and keep up with the rapid pace of technological advancements, adopting a programmatic approach to TMSs and operations is important. This approach strategically connects policies, procedures, resources, staffing, and coordination to achieve objectives that align with the organization's goals, ensuring the smooth operation of their transportation system.

The TMS program is designed to link program objectives with day-to-day activities and decisions that enhance program effectiveness. These primary elements support the agency in achieving its program objectives and ensuring effective direction and management of the TMS.

The TMS program may not exist as a standalone program but may be an element or initiative captured in the agency's TSMO program or its own program.

TSMO activities are a set of integrated, coordinated, and collaborative operational strategies that focus on obtaining the most out of the existing transportation system. Often, these strategies require coordination across multiple jurisdictions, agencies, and modes so that the transportation system works as a unified whole. As part of a TSMO program, TMS programs can aid the planning and identification of future enhancements, improvement projects, staffing, and other necessary resources to support execution of TSMO programs.

Agencies can integrate planning, operations, maintenance, and related management and administrative components into a unified program with shared goals and objectives. Based on agency practices, effective TMS programs also demonstrate the following common characteristics:

- Prioritize the provision of high-quality services.
- Establish clear, measurable, unambiguous, and documented objectives that align with the agency's goals.
- Refrain from constructing infrastructure elements that cannot be maintained and operated.
- Track and report results and outcomes.
- Actively cultivate and reward skilled personnel.
- Establish a multiyear plan capturing improvements, resources, and support needed for TMS.
- Monitor, evaluate, and report on performance.

## TMS PERFORMANCE

### TMS Performance Monitoring

Effective performance monitoring is important for successfully implementing operational strategies, managing and operating TMSs, and achieving agency goals and objectives. Performance measurement process enables agencies to gather and evaluate data about their systems to measure progress toward specific goals. These goals typically pertain to enhancing safety, improving efficiency, and meeting customer expectations. Performance measures also can be used to support future planning efforts.

Assessing system performance entails analysis of the available data, which are converted into quantifiable metrics that depict the state of the system and the system's progress toward achieving transportation system objectives. Agencies can leverage emerging technologies and visualization methods to report significant trends in the data. This information enables agencies

to make informed decisions to enhance or improve system performance and to pinpoint any issues that may lead to suboptimal system performance.

Typically, an agency will strive to align its operational objectives with specific performance measures. By having clearly defined business objectives and performance targets and using performance monitoring an agency can allocate resources effectively to achieve the specified targets. Furthermore, this information can be used to adapt an operational strategy or modify the management and operation of a TMS, ensuring continuous improvement and alignment with the agency's goals.

Performance metrics can be classified as either investment oriented or outcome oriented. Investment-oriented performance metrics focus on the resources allocated to the system, such as staff hours, expenses incurred on third-party services, or funds spent on upgrades. A higher investment in the system leads to higher expectations regarding its performance. In contrast, outcome-oriented metrics center around measuring data related to the results of the system operations. These data are used to assess the quality of service provided by the TMS, enabling agencies to prioritize resources spent on maintenance and procurement based on this information.

Agencies often establish performance measures to facilitate their TMC operations, which are aligned with agency and regional objectives. TMC performance measures should also align with the performance measurements for the entire TMS, because TMC depends on many TMS services and subsystems for the operational support. A few examples of typical key performance measures for analyzing functions of a TMS are included in table 2. For more information on TMS performance measures, refer to the report on performance measures and health index of ITS devices.[12]

**Table 2. Typical traffic management system performance measures.**

| TMS Function Category[12] | Performance Metrics |
|---|---|
| Mobility | • Delay due to congestion.<br>• Vehicle miles traveled by congestion level.<br>• Level of service.<br>• Travel time reliability. |
| Safety | • Total number of crashes.<br>• Number of secondary crashes.<br>• Construction-related fatalities. |
| Incident management | • Number of responded crashes versus total number of crashes.<br>• Incident detection rate.<br>• Roadway coverage. |

| TMS Function Category[12] | Performance Metrics |
|---|---|
| Information dissemination | • Frequency of data sharing.<br>• Extent of real-time information.<br>• Number of agencies that receive information.<br>• Reduced overall travel time. |
| Asset and configuration management | • Uptime of equipment.<br>• Mean time between failures.<br>• Average downtime for repairs. |

Performance measures for a TMS are tailored to the TMS's specific needs, operational strategies, functions, and the environment in which the TMS operates. Regular monitoring of a TMS is necessary to improve its effectiveness in achieving program goals. The data collected to support performance metrics depend on the selected measures and the type of TMS environment, such as freeways, surface streets, or integrated facilities. Agencies must consider the TMS's ability to collect and process data into a format that can be analyzed according to the desired performance measures. Performance assessment analysis may be conducted by other agency functions outside of the TMS.

When an agency is considering incorporating performance measures into their assessment, the agency should consider issues that could hinder the efficient and cost-effective operation and performance measurement of the system. The following are typical issues and examples of common challenges:

- Gaps in coverage: Freeways are typically monitored at spaced intervals in urban regions, resulting in potential gaps in between sensors.

- Latency in data collection: Jurisdictional issues, staffing limitations, and data latencies mean that agencies typically react after congestion has already formed, sometimes after secondary incidents have occurred.

- Building out and maintaining field devices and assets, and cost to build out and maintain field equipment:

    - Cost to build out or expand areas being monitored by a TMS.
    - Managing the assets.
    - Field components, such as roadway sensors and CCTV cameras, are costly to procure and maintain, resulting in significant gaps in geographic coverage and inconsistent functionality.

- Consolidation of data from multiple sources: Obtaining data from multiple sources can be challenging due to format differences, nonuniformity in geographical and temporal granularity of data, different data schema used by participating agencies, and methods of addressing multimodality of trips.

- Linking the use of data to modeling tools: Combining historic and real-time data in modeling tools requires the resources skilled enough to develop the model and incorporate nontraditional data, such as weather and incidents, into the model.

Performance assessment's main purpose is identifying areas for improvement within the TMS. Discovery of these challenges and their relevancy to the TMS needs and performance requirements can be incorporated into assessing systems and technologies, performance measures, and other CMF dimensions, which are discussed in chapter 5. These results can also be used to plan and design new TMSs or to enhance existing ones. By analyzing the operational strategies and functions of the TMS, the assessment can provide valuable insight into what aspects are working well and what aspects need to be improved to meet the objectives of the TMS. The lessons learned from the assessment can be applied to new or existing TMSs.

Agencies should consider the following areas of performance measurement during assessment:

- Determining performance measures and thresholds.
- Linking performance measures to TMS goals or objectives.
- Monitoring.
- Evaluating.
- Reporting process, plan, and methods to share information.

**TMS Performance Reporting**

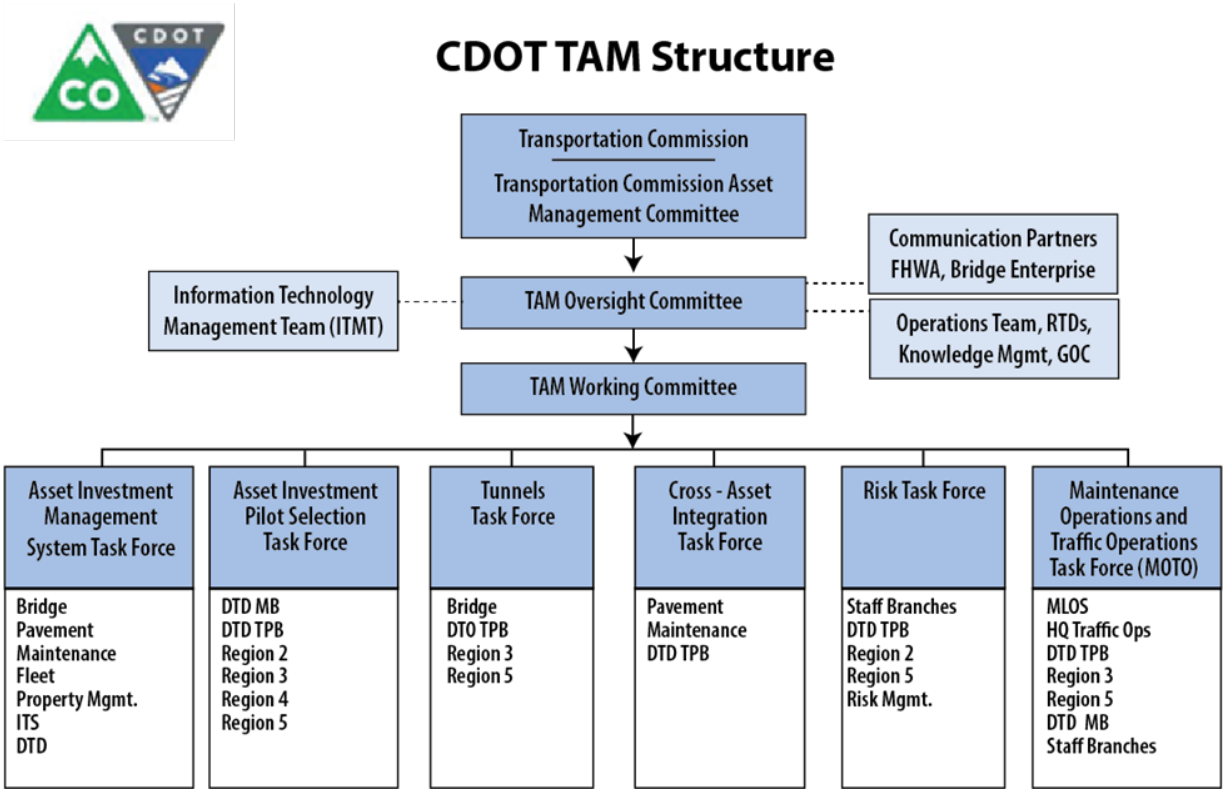
An increasing number of agencies are reporting system performance in realtime using methodologies with no latency in data output, such as dashboards or data metric visualization tools, which provide timely information for decisionmaking purposes.

Performance assessment reports should be designed to align with the agency's and region's performance reporting. This alignment allows for valuable information to be communicated to agency decisionmakers, stakeholders, and the public. The format of the reports must be suitable for the intended audience, whether the report is an informal document for internal agency decisionmakers or a formal document for external stakeholders. Reports are expected to contain information and communicate that information in a clear and concise manner, regardless of the reporting frequency.

Graphical representation of performance measures is recommended because the data are more accessible and easily understandable. Although some data visualization software solutions may be costly and challenging to implement, the benefits typically outweigh the costs. Interactive graphical representations, such as Web-based reporting, allow for multiple users to access information from different locations and can communicate more complex data messages. Some of the examples of the dashboards and reports are included in the following sections.

### Resources for Managing and Operating TMSs

The resources needed to manage a TMS, especially as relates to staffing, start with an organization chart that delineates roles, responsibilities, and, in many cases, chain of command or decisionmaking. Figure 3 shows one example.






TAM = transportation asset management; RTD = Denver Regional Transportation District; GOC = group operations center; Mgmt. = management; DTD = Division of Transportation Development; MB = Mobility Branch; TPB = Transportation Performance Branch; DTO = Division of Transportation Operations; MLOS = minimum level of service; HQ = headquarters; Ops = operations.

**Figure 3. Diagram. Sample TMS organization chart.**

The following key aspects of staff resource planning are taken from various agencies' lessons learned:

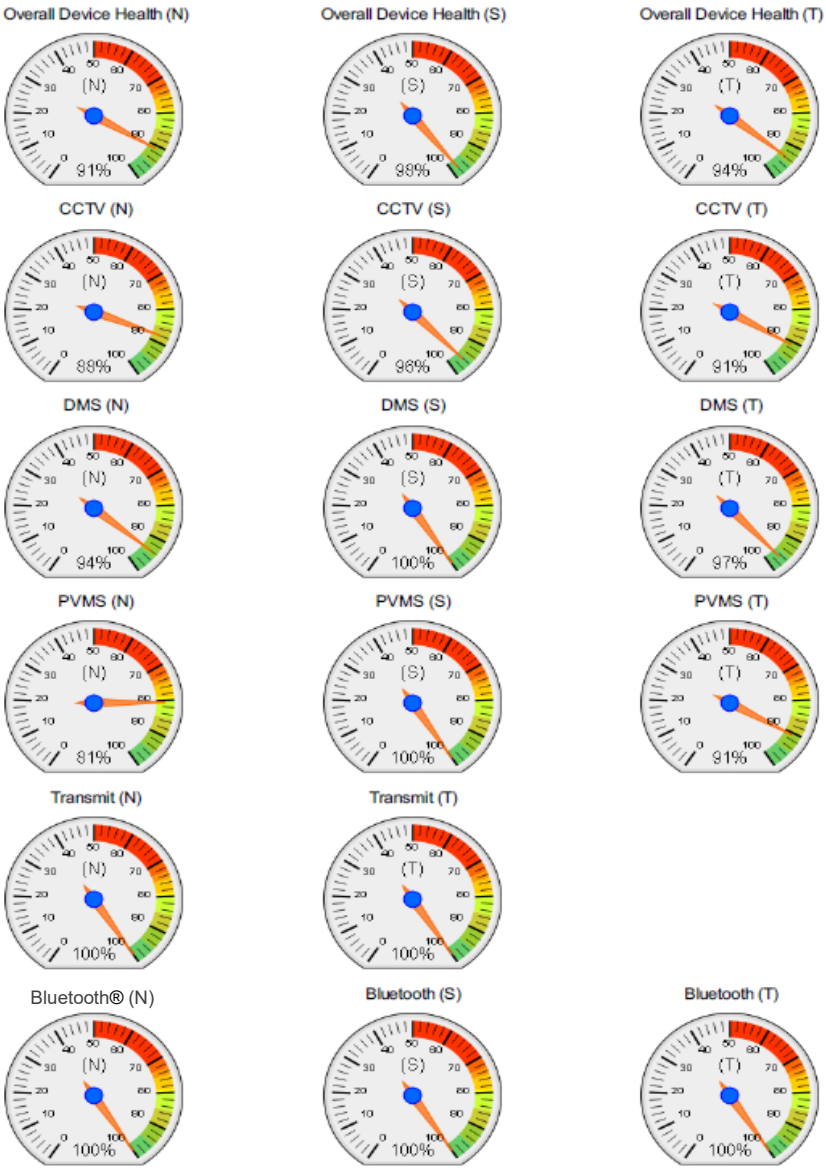
- Establish strong leadership: Having top leadership support the initiative ensures that the process is recognized agencywide.
- Promote TMS at all levels: Including TMC operations, ITS groups, IT groups, traffic management teams, incident management staff, and human resources levels.
- Include subject matter experts: During the assessment process, subject matter experts can meet to help develop performance measures and targets.

- Make documentation inviting: Including graphic artists and professional editors ensures documents are pleasing and easy to read.

- Update capabilities and staffing plans annually: Staffing often changes, and the needs and training of current staff must improve as new technologies and capabilities are introduced.

**Inventory and Condition of TMS Assets**

Inventorying TMS assets (e.g., ITS field devices) and resources (e.g., asset management tools) is the foundation of a transportation asset management program. Knowing the magnitude of assets and resources that are available and other key information, such as location, age, and condition of the assets and resources, helps agencies better manage their TMS day-to-day tasks, such as monitoring the performance and condition of the assets and resources to repair or maintain as needed. Understanding TMS asset health is a key component to correctly assessing capabilities. Figure 4 contains an example of providing asset health in a single dashboard.






N = North; S = South; T = Total; PVMS = Portable Variable Message Signs.

**Figure 4. Illustration. Example traffic management system and intelligent transportation system asset dashboard.[13]**

## TRENDS AND ISSUES TO CONSIDER

When assessing TMS capabilities and performance, agencies can consider the following trends and issues:

- Emerging technologies and data sources: A variety of new technologies and data sources are being used and can be introduced into a TMS to improve its functionality, efficiency, and ease of use. The List of Emerging Technologies and Data Sources section provides lists of emerging technologies and data sources that are relevant to a next-generation TMS.

- Increased emphasis on comprehensive agency asset management: All State DOTs are now required to develop transportation asset management programs (TAMPs), and many include TMS asset management as part of these plans. Some States are developing comprehensive asset management tools that include all resources (e.g., bridges, pavement, utilities) as well as TMS assets.

- Cybersecurity: The ITS Joint Program Office has listed cybersecurity for ITS as one of its key initiatives. Public agency IT departments are increasing cyber requirements and conformance. These IT needs should be part of any assessment of TMS capabilities and performance.

**List of Emerging Technologies and Data Sources**

This section contains lists of different emerging technologies that provide opportunities for improved TMS capabilities.

***Emerging Technologies***

Data technologies:

- Light detection and ranging.
- Laser.
- Automatic vehicle location.
- GPS and phone-based probe data.
- Crowdsourced data.
- Internet of Things (IoT).
- Cloud computing.
- Big data technologies.
- Block chain.
- Data analytics.
- Commercial transactional data.

Decision support system technologies:

- Artificial intelligence: machine learning and deep learning.
- Cloud computing.
- Edge computing.
- Voice-driven assistants.
- Data analytics.

Vehicle technologies:

- Connected vehicle.
- Automated vehicle.

Sensor technologies:

- Video analytics sensors.
- Air quality monitoring sensors.
- Smart lighting.
- Gunshot detectors.
- Wi-Fi® sensors.[14]

***Emerging Data Sources***

Connected travelers data:

- Crowdsourced data.
- Connected citizen applications.
- Crowdsourced incident and congestion data.
- Crowdsourced video.

Connected vehicle data:

- Basic safety messages.
- Probe data messages.
- Others.

Connected infrastructure data:

- Roadside dedicated short-range communication/basic safety message collection.
- High-definition signal data.
- Active traffic management (ATM) and ITS devices (e.g., signals, signs, cameras, RWIS).
- IoT.

Map technologies:

- Crowdsourced mapping data.
- High-resolution map data and other asset management systems.
- Real-time trajectory data.

Other data sources:

- Real-time turning movement data.
- Bluetooth reidentification.[13]
- Mobile sensors.
- High-definition maps.

Agencies can consider the following additional issues:

- Determine what to include to support proposed improvements and information to include in other processes to obtain needed funding, support, or resources.
- Identify other agency or regional planning processes, plans, or initiatives to incorporate the results or plans for TMS improvements.
- Identify the scope of planning effort (e.g., feasibility study, system implementation).
- Identify sources, information, and analyses to include in planning process.
- Determine what to include in plan to support of proposed improvements and information to include in other processes to obtain needed funding, support, or resources.
- Identify other agency or regional planning processes, plans, or initiatives to incorporate the results or plans for TMS improvements.

# CHAPTER 4. CONDUCTING AN ASSESSMENT

The preceding chapter delved into the TMS and various elements that can be utilized in a TMS assessment and covered TMS programs, structure, policies, procedures, resources that must be considered in an assessment, and trends affecting TMSs.

This chapter discusses the process of assessing a TMS and covers how agencies can prepare for an assessment, the assessment process, conducting the assessment, and what goes into an assessment action plan as one of the TMS assessment outcomes. The chapter addresses the following questions:

- What is required to prepare for an assessment?
- How is assessment conducted?
- What can be included in an action plan to facilitate post-assessment?

This chapter includes the following sections:

- Planning and Preparing for a TMS Assessment: Covers initial steps to prepare and plan the assessment.

- TMS Assessment Process: Discusses the step-by-step process of assessment and how to conduct the assessment.

- Assessment Outcomes: Focuses on the action plan and considerations for building organizational support.

This chapter examines each CMF dimension agencies can consider when conducting an assessment, and the activities, information, and issues to consider when preparing for or performing a TMS assessment.

## PLANNING AND PREPARING FOR A TMS ASSESSMENT

Chapter 2 briefly mentions the steps involved in conducting the assessment. This section discusses how to prepare to conduct an assessment. The next section delves into the process and steps to conduct an assessment.

During preparation and planning to support a TMS assessment, an agency may find it useful to identify the project lead and an executive champion. The lead for the assessment can coordinate and manage all the activities leading up to the actual assessment. An agency can assemble a small group to support the lead in developing the concept of the assessment, determining the assessment's scope and the outcome sought, and deciding who should be involved. The executive champion can provide management support and alignment within the larger organizational structure.

The group preparing for and supporting a TMS assessment may benefit from staff participation in planning, programming, budgeting, IT, or coordinating with external stakeholders.

Once the initial person or group responsible for leading and supporting the assessment is identified, the leaders should consider the following topics to support developing the concept to conduct an assessment:

- Determine effort and timing for the assessment.
- Identify activities to prepare for the assessment.
- Identify the information to consider and possible analysis to conduct in the assessment.

The executive sponsor may be involved in reviewing and approving the concept to pursue and conducting the assessment and securing the required resources. Once the concept is approved, the group can start meetings for planning and preparation (e.g., identify and collect information and identify stakeholders to include in the process) and then begin the actual assessment.

The group can consider the following topics in preparation of the assessment:

- Resources to conduct the assessment (e.g., identify facilitators to conduct the actual assessment).
- Activities needed to conduct the assessment.
- Availability and time to schedule meetings with the relevant people.
- Time needed from participants for meetings and workshops.
- Additional stakeholders to be included in an assessment.
- Expertise and support resources to support the stakeholders identified to perform the assessment.
- Agency sources and information needed.

## COLLECTING SUPPORT INFORMATION AND DOCUMENTS

An agency preparing for or conducting an assessment can use certain documents as input to the assessment, and those documents must be evaluated. These documents can help identify current capabilities, capture performance, and support and differentiate levels of maturity assigned to each of the dimensions.[3] This information, along with trends over time, provides a foundation to build consensus among stakeholders when discussing each dimension, identifying current capabilities and performance, and determining a level of maturity for each dimension.

The following list provides a sample of relevant policies and procedures to prepare before an assessment:

- Strategic goals and plans.
- Regional plans.
- ITS strategic plans.
- Regional ITS architectures.
- TSMO plans.
- Results of previously conducted assessments, if available, and action plans.
- Condition of TMS assets, performance measures, and dashboards.
- Traffic signal timing.
- Agency staff and training programs.
- Funding and grant programs.
- ATM traffic management plans.
- TMS plans.
- MOUs.
- Agency and project charters.

The TMS assessment should consider the existence of these resources and other documents, their relevance to TMS needs, future agency plans, and how the current organizational policies and procedures play into the development of TMS capabilities.

Some of the documents may be readily available. Some documents may need to be searched for, discovered, and analyzed. Planning staff may need to consider the following steps:

- Obtaining resources to collect information.
- Collecting necessary information and any additional data.
- Evaluating previous documents.

## TMS ASSESSMENT PROCESS

This section explores the steps to conduct a TMS assessment. The process follows the same four-step approach used for any individual assessment using the CMF framework. The CMF self-assessment process consists of the following four main steps:

1. Assemble stakeholders and answer questions.
2. Identify current capability levels.[3]
3. Review and select actions for improvement.
4. Compile an implementation action plan.

### Step 1. Assemble Stakeholders and Answer Questions

To prepare for the TMS assessment, identify the assessment's purpose, need, and anticipated outcome. Key stakeholders need to understand the process before deciding who should be involved and what information to use. Proper framing of the TMS, assessment, and potential impact is also important.

After preparing stakeholders and gathering the appropriate information, the group proceeds with the self-assessment process, which involves a series of multiple-choice questions across all CMF dimensions.[3,5] The group then reaches a consensus answer and records the answer for future reference.

During this first step of the process, the agency may consider the following issues:

- Has the agency completed any previous TMS assessments?
- Has the agency completed any self-assessments for other TMSO program areas?
- Should the agency consider referencing any TMS plans?
- Should the agency consider referencing agency or regional strategic plans, programs (e.g., TSMO), or other plans (e.g., ITS plans)?
- Should the agency consider other sources of information (e.g., TMS monitoring and reporting, TMS asset condition reports)?

Additionally, the current and future demands on an agency TMS to build support for an assessment are important for the agency to understand. As agencies actively build out their TMSO programs, new operational strategies introduce new demands on the TMS. Technology advancements (e.g., software, hardware, or field devices) provide opportunities to enhance TMS capabilities. A more informed and connected traveling public demand timely traveler information, which increases both complexity and opportunity for an agency TMS.

After an agency understands the value and opportunity of a TMS assessment, the agency should obtain appropriate resources. The entire assessment process benefits from a single person leading and managing the effort. Although the lead person is not solely responsible for determining the agency capabilities across each dimension, the lead person can organize the effort, steer the discussion, and document the results.

Including the right people in an assessment starts with understanding the staff currently supporting the TMS, as well as understanding the future demands on the TMS. Potential stakeholders for the TMS assessment may include:

- Traffic engineers.
- TSMO program staff.
- Long-term planners.
- Short-term capital budget planners.
- ITS maintenance staff.
- IT staff.
- Traffic operations center managers and operators.
- Communications and public relations staff.
- Transportation research staff.
- Partner agency representatives.

After identifying the stakeholders to include in the assessment process, the agency can determine the timing of the assessment. Providing enough time to conduct a thorough assessment is important. Scheduling a date, or dates, where all the key stakeholders can participate is also important. Certain stakeholders may only be interested in participating in certain dimensions of the assessment. Other stakeholders would be valuable to include throughout the entire assessment process.

Once the agency is ready to conduct the assessment, a kickoff discussion can start the effort. The facilitator can provide all the participants with the context, approach, and expected results of the assessment. The assessment is conducted one dimension at a time.[6] At times, specific capabilities regarding another dimension not currently being assessed may be discussed. For example, during the culture dimension, the conversation may bleed into workforce capabilities. The facilitator should be cognizant of this possibility and steer the direction back to the current dimension being assessed.

The next step of the process is to reach a consensus and record the agency responses for each question across all dimensions.[6]

**Step 2. Identify Current Capability Levels**

The second step of the process is to assess the capabilities level for each dimension based on the responses to each question.[3,6] The group works through the process of reaching a consensus and recording these responses.

During the assessment, capturing discussion notes is important. The agency's goal is to assign a current capability level for each dimension.[6] However, detailed notes are helpful for incorporating results into an action plan.

For each dimension, the assessment participants are expected to reach a consensus on the current TMS capabilities.[3,6] After the agency successfully assigns current capability levels, the agency can formulate goal capabilities.[3] The agency may find it helpful to establish the goal capability level directly after assigning the current level of capability. The nuances between each level (e.g., level 2 and level 3) will be top of mind for all stakeholders.

After agreeing on existing capability levels for each dimension, the group then reviews the results of the capability assessments as a whole and notes any adjustments that may need to be made.[3]

**Step 3. Review and Select Actions for Improvement**

The group must consider the current capabilities and performance for each dimension. This assessment is a foundation agencies can use to identify topics or areas where potential actions, changes, or future improvements could be made. On completion of the second step, agencies may notice gaps between their existing capabilities and the desired or target capabilities. The group can then review the list of recommended actions, assessing those actions' suitability based on current capability levels, and prioritize specific possible actions or improvements.[3] The group could provide example actions to generate ideas within the group, and those actions may also identify new actions for consideration.

Issues for the group to consider during this step of the process include:

- The feasibility of each recommended action.
- The priority level for each dimension.[6]
- The potential timeline for implementing proposed actions.
- The resources needed for implementing proposed actions.
- How these recommended actions will support other agency planning efforts (as illustrated in figure 3 for typical integrations)?
- The implications of implementing or not implementing proposed action items on the future agency goals.

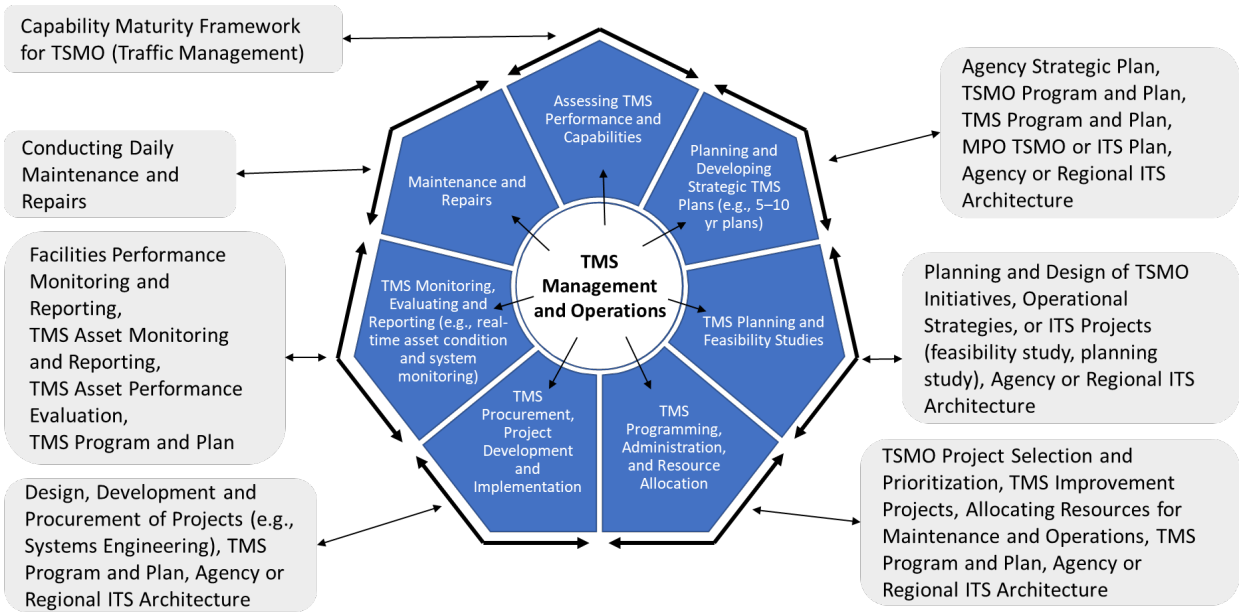
Once the group selects actions for improvement, the final step of the process is compiling all the selected actions into an improvement or an action plan.

**Step 4. Compile an Implementation Action Plan**

After completing the full assessment for each of the eight dimensions, the agency can summarize and combine the results into a final report.[6] The report can capture current capabilities as well as the goals established for each capability. Any key notes or issues identified for possible actions or improvements for an issue, topic, or dimension can also be included in the assessment report.

The action plan's goal is to clearly identify the potential changes, actions, or improvements to improve the TMS capabilities and performance. The action plan may include actionable and measurable actions or improvements. For each action, the agency should identify a lead agency or agency division that is potentially responsible for leading or participating in the activity.

Within the agency, different processes may benefit from and incorporate the results of a TMS assessment. Figure 5 shows various planning processes and plans, and how the TMS assessment results may provide information and input into these processes and plans. Additionally, figure 5 shows how information from other processes and plans may support the TMS assessment or planning for improvements.




Source: FHWA.

**Figure 5. Illustration. TMS considerations in the planning process.**

The agency TSMO program plan is an obvious place to begin incorporating the results of a TMS assessment. A TSMO plan often identifies priorities and goals for different operational strategies, establishes new performance measures, and creates individual action plans. The agency TMS serves as the nucleus of a TSMO program. Most new TSMO initiatives will eventually impact or depend on TMS performance and capabilities. The agency could update all individual TSMO program goals to incorporate action plans from the TMS assessment. For example, if the TMS assessment resulted in a recommendation to improve the redundancy of the technology running the TMS software, the TSMO plan can include this same recommendation.

Other strategic plans can be reviewed after the agency completes the TMS assessment. The agency can review the Highway Safety Improvement Program (HSIP).[15] Existing HSIP goals may be in line with future TMS capabilities. For example, the HSIP may include a goal of reducing wrong-way driver crashes. Current TMS capabilities may not include the necessary hardware, software, resources, or strategies to reduce wrong-way driver incidents. However, future TMS capabilities, as identified in the action plan, may introduce the necessary components to begin reducing wrong-way driver crashes. Any subsequent updates to the HSIP could incorporate potential impacts to TMS capabilities or coordination with future TMS enhancements.

Additionally, individual project plans (e.g., corridor plans) may benefit from the agency understanding current and future TMS capabilities. Different feasibility studies or alternatives analyses may benefit from incorporating results of a TMS assessment action plan.

The agency can also use results from a TMS assessment to identify, prioritize, and allocate future funding for TMS enhancements. In some cases, individual TMS elements (e.g., software systems or field devices) could be upgraded to improve capabilities. Other times, the agency may need to

consider a full TMS replacement project. In either case, the funding to support these efforts is a key component.

The performance of a TMS is dependent on daily operations initiatives and maintenance activities. The TMS assessment process, as well as the subsequent action plan, will likely identify opportunities to improve daily activities. In some cases, the agency can reassign or reprioritize existing resources to improve TMS capabilities. The agency can identify any opportunities to leverage existing resources to improve TMS capabilities or performance while considering the results of the assessment.

## ASSESSMENT OUTCOMES

### Action Plan

The action plan includes an agency's actions and activities aimed at improving performance. The agency creates the action plan as part of step 4 in the assessment workflow. The action plan assesses the current state of practices, which identifies opportunities for possible improvements. The plan can also outline specific activities and actions required to transition from the current capabilities or performance to a desired future state. The action plan may also identify possible timelines for any proposed action or project (e.g., programming, planning, design) implementation. The action plan can be built from the results of assessing each dimension.

Throughout the assessment process, gaps, deficiencies, and opportunities for improvement may be identified in each assessment dimension.[6] Identifying these gaps and opportunities serves as a starting point for developing an action plan that outlines the necessary steps to address these issues.

The action plan can summarize all the possible improvements identified for each dimension while considering the interrelationships between them. The agency may benefit by organizing these possible improvements by dimension or aligning them with the overall elements of a TMS program in the action plan.

The action plan can be broken down into the following types of steps:

- Identifying priority dimensions: Discussing issues relevant for each dimension (covered in chapter 2 and chapter 5); an agency may choose further focus on priority topics within each dimension in their action plan.

- Determining target capabilities: Listing capabilities that are different than current capabilities.

- Reviewing actions for each dimension: Analyzing each dimension as a result of the assessment process generates a list of follow-on actions or implementation needs.

- Prioritizing initial actions within dimensions: Identifying and prioritizing actions in a logical sequence or prioritizing actions with higher feasibility and other criteria for faster implementation.

- Compiling these actions: Compiling actions across all dimensions into a plan to improve capabilities.

- Determining necessary actions to pursue: Determining the actions and proposed improvements that were identified.

The following topics can also be included in the action plan if the topics are relevant to the agency:

- Using assessment results to improve TMS management and operations.
- Using results of the TMS assessment in other agency planning efforts.

The action plan should be tailored to the TMS program's specific needs and objectives. The action plan can outline specific actions, projects, or changes necessary to address the identified gaps and opportunities. The plan can also include a timeline for implementing these changes and an assessment of the necessary resources, including staffing, funding, and technology. The plan can also evaluate the potential impacts on business processes, workforce, management and administration, infrastructure, and systems and technology, as well as propose effective strategies for managing these impacts.

**Building Support To Address Gaps**

To build organizational support for addressing identified capability and performance gaps as a part of an action plan, agencies should clearly communicate the need for improvement and the benefits that addressing the gaps can provide. This communication can include highlighting the potential consequences of not addressing the gaps, such as reduced efficiency or increased risk. The communication can also involve sharing success stories from other organizations that have successfully addressed similar performance gaps. Involving all levels of the organization in the process of identifying and prioritizing actions or improvements to address performance gaps is also important.

This communication and involvement can help gain buy-in and support for the improvement efforts and can also provide key insights and ideas for improvement. Obtaining resources—including disciplines with the needed expertise—and providing training and support to help individuals and teams develop the skills and knowledge needed to address the performance gaps identified in the TMS assessment may also be helpful. This process can include providing tools and resources, such as templates or effective practices, to help inform the improvement process.

# CHAPTER 5. ASSESSMENT DIMENSIONS

This chapter shows how the eight dimensions of a TMS CMF can be used to assess TMSs. Additionally, this chapter examines how agencies apply the CMF to gauge their own capability levels through examples.[3] Chapter 2 provided a brief introduction to each of the eight dimensions, and some of that information is repeated in this chapter for clarity.[6] This chapter explores each dimension in greater depth to provide more information about assessing capability. This chapter includes the following specific objectives:

- Defines each of the eight assessment dimensions.
- Provides sources of information to consider using for the self-assessment.
- Introduces a range of issues to consider for each dimension.
- Provides key topics to support assessing each dimension and potential ways to differentiate levels of maturity.[3]

## ASSESSMENT DIMENSIONS

This section summarizes the eight dimensions for capabilities to be considered when assessing an agency TMS.[6] The CMF dimensions are shown in table 3. Those dimensions were previously introduced in chapter 2.

**Table 3. CMF dimensions to assess TMSs.[6]**

| Dimension or Process Areas | What Is It? |
|---|---|
| Business process | Creating plans, programs, budget |
| Systems and technologies | Establishing building systems approach |
| Performance measurement | Using performance measures |
| Workforce | Improving capability of workforce |
| Culture | Changing culture and building champions |
| Collaboration | Improving working relationships |
| Management and operations | Managing and operating daily |
| Maintenance and repair | Conducting daily maintenance and repairs |

The CMF allows agencies to examine the manner in which agencies attain objectives and understand current capabilities at each level.[3] The levels of possible attainment were briefly listed in chapter 2. The following items highlight distinctions between different levels of capabilities:

- At level 1, agencies often rely on individual champions to achieve agency goals. Due to limited resources to support program management, the risk of losing key individuals may impact the agency's ability to achieve its objectives and maintain success and may cause the agency to become nonperforming.
- At level 2, agencies have established processes that are routinely followed to minimize the risk of losing key individuals. Level 2 agencies tend to devote more of their resources

to program management functions, which helps ensure that the agency can continue to operate effectively, even if key people leave. The agency's focus on following established processes can present a risk that the agency will become too focused on adhering to those processes rather than on achieving the desired outcomes. These agencies should balance process adherence and outcome attainment.

- At level 3, agencies can measure the effectiveness of their processes in achieving their objectives. These agencies have continuous improvement processes fully integrated into their culture and can consistently improve their ability to sustain pursuit of their objectives over time. These agencies can also dedicate greater investment in resources to support and maintain program management tools and processes.

- At level 4, agencies continuously improve their processes through optimization to support the reliable and efficient attainment of their objectives. The key for level 4 agencies is achieving their stated objectives at lower risks while simultaneously optimizing their resources and investments for process measurements and control.

During the assessment process, these capability levels are applied to each of the CMF dimensions.[6] The four incremental levels of capability maturity assess the current state of maturity and identify improvement targets for each program area. By comparing levels of attainment along each of the CMF dimensions, conclusions can be drawn about most appropriate level reflecting the level of capabilities in the dimension. Also, if an organization knows the current level and reflects on the next level, the organization can recognize needs and necessary strategies for improvement.

The next section discusses each of the dimensions and how organizational practices are reflected into the range of maturity levels.[6]

## APPLYING DIMENSIONS TO TMS ASSESSMENT

Separate sections are provided for all eight dimensions. For each dimension, the following topics are discussed:[6]

- Potential sources of information to support the assessment.

- A range of issues to consider for each dimension.

- Key topics to discuss during the assessment.

- Resources for how to differentiate between maturity levels for each of the assessment dimensions.[3]

### Business Process

The business process dimension refers to programming, planning, budgeting, project development, and any agency effort that governs TMS resources, contracts, or priorities.[6] An agency TMS may depend on staff managing and operating the system, staff maintaining TMS assets, contracts enabling data integrations, software maintenance contracts, training on core

TMS capabilities, long-term planning efforts to enhance TMS capabilities, transportation plans using the TMS to achieve program results, funding to enhance the TMS capabilities, or funding to procure a next-generation TMS.

Agencies should consider the following sources of information when assessing the business process dimension:[6]

- Agency TMS plans.
- TSMO plans.
- Agency funding programs.
- TMS maintenance contracts.
- Management and operations contracts.
- Data procurement contracts.

When assessing business processes that impact TMS capabilities and performance, agencies should consider the following questions:

- How mature and standardized are agency processes related to planning for, funding, and provisioning staff or resources to support the TMS operations?

- How is a TMS replacement project funded and supported?

- How indepth is the TMS-related training of employees who spend most of their time using TMS assets or resources? How often does this training material undergo review and improvement?

- Is agency funding for TMS enhancements sustainable?

- Do priority agency programs (e.g., a highway safety program or TSMO program) identify the TMS as a primary resource to achieve program results?

When differentiating levels of maturity, agencies should consider how directly the TMS impacts existing agency TSMO priorities. For example, a level 1 capability may have limited direct impact on any existing TSMO program or process.[3] A higher level of capability may have some direct impact on an existing TSMO process or priority initiative.

To differentiate between various levels of maturity, another factor agencies should consider is funding for TMS maintenance and enhancements.[3] A level 1 capability may not have any sustainable funding dedicated to TMS maintenance or improvements. A level 2 capability may have some funding allocated, potentially for maintaining the current TMS functionality. At level 3, dedicated funding for TMS is part of a larger funding program, such as a TSMO program. A level 4, capability could be characterized by having enough dedicated funding to maintain and enhance the TMS functionality, which significantly contributes to achieving agreed-upon TMS performance goals.

**Systems and Technologies**

The systems and technologies dimension considers the use of systems engineering, systems architecture standards, interoperability, and standardization of the agency TMS.[6] Each individual TMS asset, component, and resource may be impacted by any of these processes.

As it relates to a TMS assessment, this dimension should be broadened to encompass all technologies of the TMS and consider whether the existing technologies will meet the future needs of the agency as newer technologies are adopted.[6]

Agencies should consider the following sources of information when assessing the systems and technology dimension:[6]

- Approved products lists.
- ITS architecture.
- Feasibility studies.
- Agency or regional plans.
- TMS procurement documentation.
- TMS data architecture diagrams.
- TMS, ITS, or IT design related requirements (e.g., specifications).

When assessing systems and technologies that impact the TMS capabilities and performance, agencies should consider the following questions:

- Are the agency's TMS software, hardware, data, communication, and field devices able to meet current and future TMS demands?

- How are individual TMS roadside assets maintained? By internal agency staff? Or external contractor personnel?

- How interoperable are the various systems, subsystems, components, and devices?

- Are the agency's TMS software, hardware, data, communication, and field devices able to meet current and future TMS demands?

- How does the agency assess and adopt new TMS features and TMS abilities?

- Does the agency use the ITS architecture to identify TMS integration opportunities or define the future TMS functionality roadmap?[2]

- Does the agency use the systems engineering process to introduce new TMS functionalities, enhancements, assets, or integrations?

To distinguish between different levels of maturity, agencies should consider how field devices are upgraded.[3] At level 1, obtaining new devices may be difficult due to legacy procurement issues, and not all field devices may be Internet Protocol (IP) connected (IP-connected). As an agency's capability increases, replacing and updating field devices becomes more

straightforward, and all devices can be procured, installed, and connected through a standardized approach. At the highest levels of maturity, the agency may have implemented a standardized field device replacement process to keep up with technology obsolescence cycles.

When an agency examines the capability maturity of that agency's TMS, considering software is important.[3] At lower levels of maturity, multiple software modules may be in use, which may not be interoperable. However, as maturity increases, the software application becomes more modular and interoperable, providing a seamless user experience. The user interface becomes more intuitive and user friendly. Additionally, the agency has a comprehensive software enhancement plan in place, allowing the agency to keep the software updated to meet needs and performance measures, which helps ensure optimal performance of the TMS.

**Performance Measurement**

The performance measurement dimension assists an agency in determining program effectiveness, determining how incremental changes impact system performance, and informing decisionmaking.[6] Operational performance measures demonstrate the extent of transportation problems, and agencies can use those performance measures to make the case for prioritizing initiatives that impact or utilize the agency TMS. For a TMS, performance measures can include the indirect impact on roadway mobility as well as technical performance of the TMS itself.

Agencies should consider the following potential sources of information when assessing the performance measurement dimension:[3,6]

- Mobility reports.
- Business intelligence dashboards.
- TMS databases.
- TMS reports software modules.

When assessing performance measurement impacts on TMS capabilities and performance, agencies should consider the following questions:[6]

- How complex is the agency TMS's ability to measure effectiveness and performance?
- Does the TMS have the capability to measure overall system performance, or only individually observed metrics?
- How much does the agency trust the TMS-generated performance measures to support strategic agency planning, individual transportation program planning, system improvement plans, or any other agency planning efforts?
- How is the technical performance of the TMS itself measured and reported?
- How often are the TMS functions and TMS performance assessed?

To distinguish different levels of maturity, agencies should consider the thoroughness and usability of the TMS performance measures.[3] At lower levels of capability, data generated or collected to support TSMO program performance measures are limited. At higher levels of capability, data are routinely generated, collected, analyzed, collated, and shared with all internal and external stakeholders. Additionally, the TMS-generated performance metrics enable a comparison of current performance to historical trends.

When differentiating levels, agencies should also consider the institutionalization of TMS performance measures.[3] At lower levels of capability, buy-in from key stakeholders may be limited, and the use of performance measures may be sporadic. At higher levels of maturity, the application of TMS performance measures is well established, with program managers and other key stakeholders incorporating TMS performance measures into their decisionmaking process. TMS performance measures also inform real-time operational decisions at higher levels of maturity.

**Workforce and Organization**

The workforce and organization dimension considers staff and other resources that support TMS procurement, operations, maintenance, management, and enhancements, as well as other organizational considerations that impact the agency TMS.[6]

This dimension focuses on program management and how staff is recruited, structured, developed, and retained.[6] Staffing and staff development can be common issues for TMS operations. As new technologies and strategies are developed, TMS personnel will need new, specific KSAs.

Potential sources of information agencies should consider when assessing the workforce dimension include:[3]

- Position descriptions.
- Tables of organization.
- Training programs.
- Management plans.
- Human resources plans (e.g., succession plans).

When assessing the workforce impact on the TMS capabilities and performance, agencies should consider the following questions:[3]

- How well can agency staff support, leverage, enhance, and use the TMS to achieve the overall TMS objectives?

- How well defined is the organizational responsibility for TMS performance?

- Do key agency positions that support the TMS have formal succession plans?

- How indepth is training for the key agency TMS workforce?

- How much of the TMS is supported by staff who are available 24 h a day, 7 d a week, 365 d a year?

- How does the agency expand key staffing roles as the number of TMS assets continues to increase, and the TMS continues to increase in complexity?

To distinguish between levels of capability, agencies should consider how the staff is organized. Staff without clearly defined roles may indicate a lower level of capability, and no staff or group of staff fully responsible for TMS performance may have been defined.[3] Higher levels of capability are characterized by staff who are organized with clear authority and accountability, as well as collaborative relationships among all staff members.

Agencies can also differentiate levels of capability by considering position descriptions and KSAs.[3] Lower levels of capability may lack the KSAs needed to manage and operate the TMS components. However, at higher levels of capability, the agency may have updated position descriptions to include these needed KSAs, as well as updated HR procedures for staff recruitment, retention, and development. At the highest level of capability, the agency continuously adjusts roles and responsibilities to ensure maximum operational effectiveness.

**Culture**

The culture dimension considers overall agency expectations, values, and presuppositions regarding the importance of the TMS, TMS-enabled strategies, and individual TMS components.[3,6] The culture dimension considers whether TMS-related processes are incorporated into the broader agency strategic plans.

Some agencies have a culture that encourages innovation. For these agencies, efforts to increase TMS capabilities are often encouraged and supported across the agency. Other agencies resist adopting new technologies to avoid further impact on limited agency resources. For these agencies, the culture may impede the ability to grow TMS capabilities and performance.

Culture also considers how well existing staff cooperate and how much each staff member feels a connection to impacting meaningful performance measures. In some cases, a workforce may feel a sense of pride and togetherness. In other cases, rifts may exist between different work groups. An agency may have the most technically sound and advanced systems powering their TMS. However, if each contributor is unmotivated or disengaged, this culture could severely reduce the TMS effectiveness.

Agencies should consider the following potential sources of information when assessing the culture dimension:[3]

- Agency mission and vision statements.
- TSMO program plans.
- Safety improvement plans.
- Top-level agency organizational structure.
- Agency funding line items.
- MOUs or partnership agreements with key partner agencies.
- Agency website, social media, or press releases.

When assessing the impact of culture on the TMS capabilities and performance, agencies should consider the following questions:[3]

- Is the agency TMS seen as a key resource in achieving the agency's overall goals?
- Do agency staff working with the agency TMS have pride in their work and feel as if they are performing important work?
- How many agency divisions have awareness of, integrations with, or ongoing discussions regarding the role of the TMS in achieving individual goals?
- Are TMS capabilities (existing or potential capabilities) incorporated into project alternatives analysis discussions?
- Is the agency TMS supported as top tier IT infrastructure?

When differentiating levels of capability, agencies should consider workforce participation.[3] At lower levels, agencies may lack metrics to measure impact, and individuals may not fully understand their roles in the TMS functions. At higher levels, well-defined workforce metrics and a clear understanding of roles allow everyone to influence performance measures effectively.

Agencies can also differentiate levels of capability by considering the adoption of innovation.[4] At lower levels of capability, the agency may be resistant to adopting new technologies, perceiving them as risky or potentially adding demands to an already stretched workforce. However, at higher levels of capability, the agency encourages innovation and frequently adopts new technologies, nimbly leveraging the benefits to enhance operations.

**Collaboration**

The collaboration dimension considers partnerships with other public agencies, first responders, or private partners.[3,6] This dimension highlights the importance of relationships between other transportation agencies, public safety agencies, and the private sector. Different forms of collaboration can make a TMS more effective and mature.

Collaboration can take place between systems or between people. These relationships can encourage cross-jurisdictional traffic management solutions and increase coordination of similar

efforts (e.g., work zone lane closure coordination). System-to-system collaboration highlights the ability of a TMS to integrate with other systems and data sources. People-to-people collaboration highlights the ability of individuals in the same organization to share information and coordinate their efforts.

Agencies should consider the following potential sources of information when assessing the collaboration dimension:[3]

- Agency MOUs.
- Agency data-sharing agreements.
- Regional traveler information systems.
- Regional committees (e.g., TIM oversight committees).

When assessing the impact of culture on the TMS capabilities and performance, agencies should consider the following questions:[3]

- Does the TMS support cross-jurisdictional activities?
- Does the TMS consume any data or integrations from agency partners?
- Does the TMS expose data or enable data integrations for other partner systems or technologies?
- How much communication with the public does the agency TMS encourage or enable?
- How aware of the TMS capabilities are regional partners or planning organizations?

When differentiating levels of maturity, agencies should consider any regional goals and objectives.[3] At lower levels of maturity, little to no coordination may occur between regional partners. At higher levels of capability, agencies formalize partnerships through MOUs, with clearly defined roles for each partner and a coordinated effort toward common goals.

Agencies can also differentiate levels of maturity by considering resource sharing.[3] At lower levels of capability, barriers may exist, or agencies may lack knowledge regarding the resources available from the TMS or those resources that could enhance the TMS. At higher levels of capability, partner agencies may have shared resources, such as funding or projects, to advance their common initiatives. Agencies may also want to consider whether the partners have the capability to effectively manage and leverage these shared resources to achieve the agreed-upon objectives.

**Management and Operations**

The management and operations dimension considers the day-to-day support of TMS functions and daily use of TMS strategies.[6] Many TMSs are operated 24 h a day, 7 d a week. Different approaches may be taken to manage and operate TMS resources.

In most cases, TMC staff are responsible for the primary TMS operations. During normal business hours, the TMC staff may have management available to support TMS operations.

Outside of normal business hours, the TMC may become more self-sufficient in handling TMS operations (e.g., TIM). The management and support structure can either hinder or support TMS operations.

Agencies should consider the following potential sources of information when assessing the management and operations dimension:[3]

- TMC operating procedures.
- TMC operations position descriptions.
- TMC and TMS startup and shutdown procedure documents.
- Traffic control plans.
- Interagency and multijurisdictional coordination plans.
- Continuity of operations plans that incorporate TMS operations.
- Remote command and control planning documents for TMS functionality.

When assessing the management and operations of the TMS, agencies should consider the following questions:

- How much redundancy exists among staff responsible for operating the TMS daily?
- Does the agency have a continuity of operations plan for emergencies impacting TMS functionality?
- Are all components of the TMS supported 24 h a day, 7 d a week?
- How empowered are the operations staff to make decisions in realtime?

When differentiating levels of maturity, agencies should consider the existing support structure and service-level agreements.[3] At lower levels of capability, support is often reactive and not provided in a timely manner. At higher levels of capability, the agency may have clearly defined service-level agreements with staff who are available to promptly diagnose and resolve any real-time issues with TMS performance.

Agencies should also consider the decisionmaking ability of staff. At lower levels of capability, only a small number of staff may have the authority to make decisions, which may hinder TMS efficiency or effectiveness.[3] At higher levels of capability, decisionmaking responsibilities are more flexible, and all staff members understand how to leverage each TMS element to maximize operational effectiveness.

**Maintenance and Repair**

The maintenance and repair dimension considers ongoing support of TMS functionality and enhancements and condition monitoring and upgrading of individual TMS elements.[6] TMS failures significantly impact travel performance, safety, and reliability. Agencies incorporate maintenance into the planning and design of a TMS program by specifying how the TMS will be monitored, how the agency will plan for and react to system malfunctions, and the resources required to maintain the TMS.

System durability and dependability is also tied into maintenance and repair. Ideally, a TMS, as well as individual TMS components, is available almost 100 percent of the time. Even during routine updates, agencies prefer not to take TMS functionality offline.

Agencies should consider the following potential sources of information when assessing the maintenance and repair dimension:[3]

- ITS maintenance contracts.
- ITS support staff position descriptions.
- TMS software support contracts.
- TMS IT hardware support escalation procedure documents.
- TMS asset inventories.

When assessing the maintenance and repair of the TMS, agencies should consider the following questions:

- How does the quantity of TMS assets in operation compare to the agency's TMS asset inventory on hand for replacing key TMS assets?
- Are TMS components, subcomponents, and integrations maintained in a prioritized method?
- Are TMS components reliable?
- Does the TMS use an industry-standard network monitoring tool to monitor all subsystems and components and notify key personnel when an issue arises?
- Do individual TMS components have separate and prioritized maintenance schedules?
- Does the agency maintenance management system and software include TMS assets?
- Is the TMS hosted on a redundant system?

When differentiating levels of maturity, agencies should consider the TMS maintenance structure.[3] At lower levels of capability, maintenance may be reactive, with repair only being made when issues arise. Agencies may also lack clear maintenance plans and documentation of repairs. At higher levels of capability, maintenance is more proactive, with scheduled maintenance plans, clearly documented repairs, and a dedicated maintenance team responsible for the upkeep of TMS assets.

When differentiating levels of maturity for real-time maintenance and repair, agencies should also consider the TMS's historical performance.[3] At lower levels of capability, agencies may not collect or use historical performance data effectively to inform maintenance and repair decisions, which may result in a higher likelihood of system failures. At higher levels of capability, the agency collects and analyzes historical performance data to identify areas of potential failures and plans for proactive maintenance and TMS asset replacements.

# CHAPTER 6. ASSESSMENT OF TMS CAPABILITIES—CURRENT PRACTICES

This chapter provides information about current practice for assessing TMS capabilities and performance. This chapter primarily provides agencies with the benefit of the experience of other agencies in framing and conducting a TMS assessment. This chapter discusses the methods and processes that agencies use, reviews the various information sources to which an agency may have access, and describes approaches that may be useful to capture the necessary information to conduct the assessment. This chapter also describes how an agency can obtain and organize the information and support that is needed to conduct the assessment. This chapter discusses issues to consider when preparing for and conducting the assessment and describes how elements of the TSMO program can be leveraged to support the assessment.

This chapter builds on previous chapters that describe in detail the processes, information, and tools available for conducting a TMS assessment. This chapter also provides information from agencies that have conducted assessments or implemented tools or methodologies to support a TMS assessment.

The information in this chapter is presented in the following sections:

- Current Agency Practices.
- Gaps in Practice.
- Issues to Consider.
- Leveraging the TSM and Operations Program.

## CURRENT AGENCY PRACTICES

As discussed in chapter 4, TMS self-assessment efforts are one of the key processes in the lifecycle of a TMS. The information captured through a TMS assessment serves as a key input for other processes, which support setting the strategic direction, planning improvements, and allocating resources for managing and operating a TMS (figure 5). Agency processes for TSMO CMFs may include TSMO, active transportation management, and traffic management plans.[3]

As the diagram (figure 5) indicates, the self-assessment effort is directly tied to strategic planning, feasibility studies, programming and resource allocation, procurement, and TMS monitoring and evaluation, which means that the assessment effort may consider how the TMS supports priorities in each of these areas. When an agency engages in a TMS self-assessment effort, the agency may intend to examine how well the agency's approach to TMS planning, definition, design, analysis, procurement, development, implementation, and operation align with organizational goals, initiatives, resources, and priorities for TMS operations.

Assessing a TMS involves understanding how these elements of a TMS program and assessment dimensions relate to and support operations within each component of the organization.[3,6] The TMS assessment also involves gathering, interpreting, and collaborating on a comprehensive knowledge base regarding the foundational components of each TMS program element, including the mechanisms used to accomplish specific outcomes.

Conducting a TMS assessment typically involves a concerted effort to coordinate with all the organizational units that are responsible for managing and conducting the activities within each assessment dimension. These entities are the custodians of information about goals, objectives, procedures, expectations, and output requirements necessary for decisionmakers. The agency should appropriately engage every organizational unit with a stake in the TMS at the outset to define and implement a viable and productive assessment framework.

Once the agency gathers the necessary information, the agency can develop a process to capture or collate results from each assessment dimension.[33,6] Chapter 4 of this report examines the assessment process indepth using the CMF. The sections following this chapter describe how some agencies have chosen to conduct TMS assessment activities, what methods and tools those agencies use, what gaps exist between these approaches, how the capability maturity model is applied to TMSs and what issues agencies should consider as those agencies' TMS assessment and reporting activities mature.[3]

Given the extensive range of information associated with TMS operations, the sources of information for assessment can be numerous and diverse in their focus. Agencies that engage in a TMS assessment or some related activity may consider the documentation in table 4 useful information sources. The most obvious and potentially valuable information source is the documentation of prior assessments. The most relevant would be those sources consistent with the CMF and current agency priorities.[3] However, any related documentation is valuable. At a minimum, these assessments reflect what was considered acceptable and relevant at the time that the assessment was completed.

**Table 4. Baseline reference documentation for TMS assessments.**

| Document Type | Relevance to TMS Assessment |
|---|---|
| Agency strategic plans | These plans are agency-level documents that typically state overall performance goals, long-term investment plans, and immediate priorities. These plans are useful for information regarding the formulation of performance metrics meaningful to executives and other decisionmakers. |
| TSMO strategic plans | These plans articulate strategic goals and objectives, why TSMO is important, and what the agency wants to achieve. These plans are immediately relevant because TMSs are a principal mechanism for the delivery of transportation system capabilities and performance and typically offer information at a level of detail that is very useful for assessing the TMS. |
| TSMO implementation plans | These plans typically define strategies and projects in the strategic plan. These plans can help further focus the assessment approach for specific TMS elements and related performance metrics. |
| TSMO business plan | These plans articulate how the program operates and the responsibilities of organizational units for TSMO services, projects, and activities. These plans are useful, at a minimum, for defining the organizational units that should be engaged in the assessment-planning process to determine what constitutes successful capabilities and performance thresholds. |
| TMS strategic plans | Due to their purpose and nature, TMS plans and feasibility studies should provide the most direct information regarding what assessment is needed to effectively plan for TMS investment and how various technologies should be evaluated. |
| TAMPs | These plans provide information about the assets, the asset management strategies, long-term expenditure forecasts, and business management processes. These plans are an important agency tool to demonstrate how the agency achieves its mission. These plans are tactical-level documents that focus analysis, options development, programs, delivery mechanisms, and reporting mechanisms on ensuring that strategic objectives are achieved. |
| ITS architectures | These architectures are key to understanding how the various TMS components function, particularly regarding other component elements. This integrated picture provides important context for agencies formulating metrics for capabilities and performance in the context of the overall TMS. |

| Document Type | Relevance to TMS Assessment |
|---|---|
| TMS inventories and TMS asset documentation | These tools and databases for managing TMS assets offer the agency information relevant to assessment by allowing access to data about asset age, condition, configuration, maintenance history, and current operational status. These data are key inputs to assessment framework and methodology. |
| Information on TMS performance measures | Performance measures are a foundational component of any assessment and constitute the objective, quantitative, and qualitative basis for defining TMS effectiveness. At a minimum, these performance measures typically include the following measures:<br>• Traffic (e.g., counts and speeds).<br>• Travel conditions (e.g., delays, incidents, and travel time).<br>• Crashes (e.g., location, type, and severity).<br>• Events (e.g., road closures and planned special events).<br>• Status and condition of TMS assets (e.g., operating and online or offline). |
| Existing and previous assessment documentation | Documentation of previous assessments, regardless of whether those assessments follow the CMF approach, is very valuable. At minimum, previous assessments offer information about agency priorities, measurement methods, output needs, and data collection and analysis processes. |

These previous assessments can be a particularly valuable source of information related to metrics and assessment methods. Planning documents also are important for effective assessment preparation. Agencies with TMS typically possess a similar set of baseline references, which became evident during this study. These documents include those shown in table 5.

Research conducted for this study indicated that the CMF model could be applied to TMS assessment (provided that some methodology gaps are addressed), even though the CMF model was not developed for that purpose.[3] This analysis found that the existing CMF model information most applicable to TMS assessment is the framework developed for traffic management CMF. Previous FHWA-sponsored research examined how the traffic management CMF could be applied and what steps might be necessary to close the methodology gaps. Table 5 summarizes these findings.

**Table 5. Applying the traffic management capability maturity framework to TMSs.[11]**

| Description | For Assessing TMSs |
|---|---|
| Business process: Business processes, in the context of traffic management, refer to planning, programming, agency project development processes, and those organizational aspects that govern various technical or administrative functions (e.g., training, human resource management, contracting and procurement, IT, or coordination). In many cases, the business process elements go beyond the day-to-day operational activities and require broader institutional support and involvement to address. All these processes are fundamental to the success of operations and management activities. | • Planning processes:<br>  ○ Tier 1: Integrate TMSs as a TSMO element in long-range transportation plans by MPOs or State DOTs.<br>  ○ Tier 2: Develop TMS self-assessment capability.<br>  ○ Tier 2: Develop 5–10-yr TMS strategic plans (purpose, vision, goals, and objectives).<br>  ○ Tier 2: Integrate TMSs in TSMO operational concepts and strategies.<br>  ○ Tier 3: Conduct TMS planning and feasibility study.<br>  ○ Tier 3: Plan process for acquiring new or improving TMSs (e.g., concept of operations).<br>  ○ Tier 4: Implement TMS procurement and contracting.<br>  ○ Tier 4: Establish TMS project design, development, and implementation process.<br>  ○ Tier 4: Identify TMS programming, resource allocation, and budgeting process.<br>  ○ Tier 5: Identify TMS programming and allocation of resources for day-to-day operations.<br>• Clearly defined organizational structure for advancing TMS initiatives or projects.<br>• Organizational and administrative processes: Day-to-day workflow activities that support TMS operations.<br>• Maintenance.<br>• Asset management processes. |

| Description | For Assessing TMSs |
|---|---|
| Systems and technology: Using appropriate processes to design and implement systems will ensure the agency appropriately addresses regional needs, implements systems in an efficient manner, and achieves interoperability with other systems. | • TMS feasibility study:<br>  ○ Technical feasibility.<br>  ○ Operational feasibility.<br>• Economic feasibility. |
| Performance measurement: Performance measurement is key to determining program effectiveness, determining how changes are affecting performance, and guiding decisionmaking. Operations performance measures demonstrate the scope of transportation issues and can be used to advocate for operations within an agency, among decisionmakers, and the traveling public. Additionally, performance measures showcase the accomplishments that the agency achieved with public funds in the transportation system. | • Define performance measures.<br>• Assess performance:<br>  ○ TMS performance.<br>  ○ Operational strategies.<br>  ○ Roadway and transportation system impact.<br>• Key capabilities to support performance measurement:<br>  ○ Monitoring TMS assets, operational strategies, and transportation system.<br>  ○ Collecting, processing, storing, and managing data.<br>  ○ Evaluating collected data.<br>  ○ Reporting performance. |
| Day-to-day management and operation of system and center: Day-to-day management of a TMS in a TMC requires thoughtful development of policies, plans, and protocols. | Day-to-day management and operation of TMS and TMC:<br>• Operational policies and procedures.<br>• Traffic control plans.<br>• Protocols for sharing information.<br>• TMS and TMC operations emergency plan.<br>• TMS and TMC malfunction response.<br>• Interagency and jurisdictional coordination plan; TMS and TMC startup and shutdown procedures.<br>• Agreements, contracts, and MOUs.<br>• Staffing and work shifts. |

| Description | For Assessing TMSs |
|---|---|
| Organization and workforce: Efficiently executing processes that support effective programs requires the appropriate combination of coordinated organizational functions and technical qualified staff with clear management authority and accountability. | Staffing and workforce development:<br>• Identify staffing needs through CMM and CMF assessments and systems engineering process.<br>• Define staffing approach (i.e., in house, contracted, or hybrid).<br>• Develop staffing plan.<br>• Define job descriptions (i.e., KSAs) for TMC and TMS positions.<br>• Define recruitment strategies (i.e., partnering with human resources and targeted advertisements).<br>• Train, develop, and certify staff.<br>• Define policies regarding staff scheduling (i.e., work hours, remote, and operations 24 h a day, 7 d a week).<br>• Retain staff and institutional memory through job satisfaction and competitive salaries. |

| Description | For Assessing TMSs |
|---|---|
| Day-to-day maintenance and repair of system and center: Maintenance is important for keeping a TMS running in the manner for which the TMS was designed. Lack of maintenance leads, almost inevitably, to escalating decline. Identifying issues and activities associated with TMS and TMC maintenance is key. | Day-to-day maintenance and repair of TMS and TMC:<br>• Define TMS maintenance and repair policy:<br>  o Preventive maintenance versus responsive maintenance.<br>  o Quality control criteria.<br>• Develop TMS maintenance program: Establish an approach to procuring maintenance services and products—contractor maintenance versus in-house personnel.<br>• Implement maintenance management system and software.<br>• Document traceability and configuration management.<br>• Document traceability and configuration management: Create maintenance plan—staffing qualification, cost estimates, and performance measures.<br>• Establish maintenance procedures for TMS and TMC lifecycle.<br>• Reallocate maintenance resources. |
| Culture: Culture is the combination of values, assumptions, knowledge, and expectations of the agency in the context of the agency's institutional and operating context and as expressed in the agency's accepted mission and related activities. | • Promote and embed TMS objectives throughout the agency and partner business practices.<br>• TMS should be incorporated into:<br>  o Agency strategic plans.<br>  o Agency TSMO plans.<br>  o Agency operational plans.<br>  o Agency safety plans.<br>  o Agency asset management plans. |

| Description | For Assessing TMSs |
| --- | --- |
| Collaboration: Developing and implementing TSMO requires a collaborative approach. The effectiveness of most strategies depends on improving the coordinated performance of each partner. | Communicate and interact with the correct internal and external stakeholders. For example, when developing incident management plans, there should be stakeholders from the following groups:<br>• Law enforcement.<br>• Emergency medical services.<br>• Fire and rescue.<br>• Traffic operations team and TMC staff.<br>• Towing and recovery. |

This project examined several case studies from earlier research and agency interviews as a basis for applying CMF for TMS assessment.[3] The relevant conclusions from these activities are summarized in the following sections.

**Business Process**

Through a series of CMM assessments, Pennsylvania DOT (PennDOT) was able to document nine program needs that translated into strategies tied to the six different capability maturity dimensions (business processes, system and technology, performance management, organization and staffing, culture, and collaboration).[3] These strategies translate further into individual actions that PennDOT will be working on as part of the agency's improvement efforts. As an example, one of the performance measurement strategies is continuing to develop a performance measure program, while several associated actions for that strategy include developing traffic signal performance measures and developing tools to predict work zone congestion more accurately. This program plan is helpful for business processes such as planning and scoping.

Ohio DOT (ODOT) developed a tool called the Traffic Operation Assessment Systems Tool (TOAST) to determine operationally sensitive corridors by making data-driven decisions.[16] TOAST segments routes and scores for each route depend on data categories and weighting factors. The higher the score TOAST generates, the better the route is performing, while lower scores indicate the route could benefit from TSMO strategies. These calculations are helpful for business processes, such as prioritization, programming, budgeting, and procurement. Figure 6 shows a screenshot of the tool.

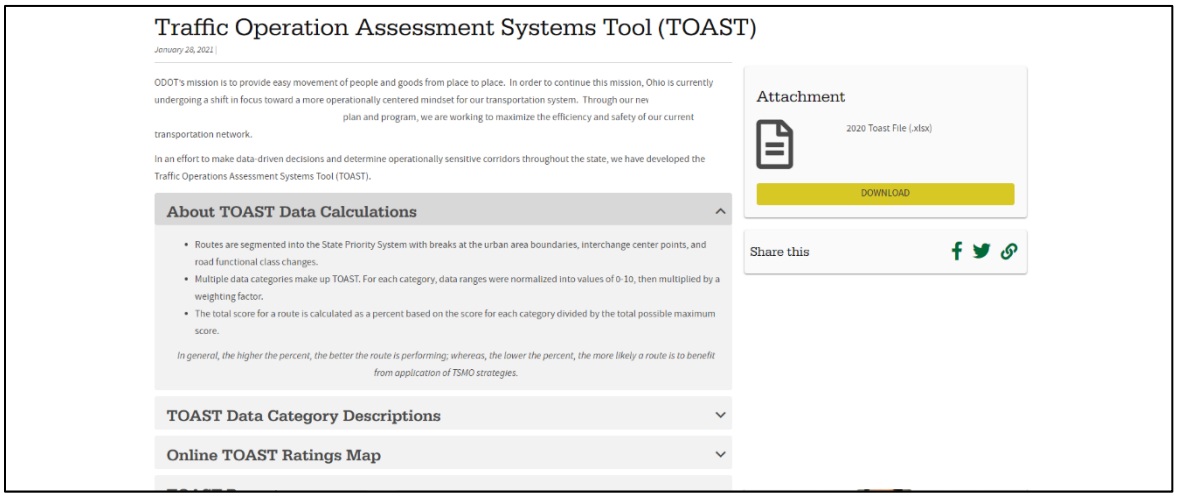




**Figure 6. Screenshot. ODOT TOAST.[16]**

Interviews conducted for this study offer additional insights into TMS assessment as TMS assessment relates to business processes. These findings are summarized in the following sections.

### System and Technology

Florida DOT (FDOT) developed and deployed a statewide software platform used in all 12 of FDOT's TMCs.[17] With all common TMC functions standardized, the TMCs are interoperable and can serve as backups for each other, with one DOT district able to control TMC assets in a different district in case of an emergency.

Interviews conducted for this study offer additional insights into TMS assessment as TMS assessment relates to systems and technology. These findings are summarized in the following sections.

### Performance Measurement

Figure 7 presents a dashboard that measures highway statistics and Virginia DOT (VDOT) performance in several key areas, including safety, projects, asset conditions, finances, citizen satisfaction, and management.[18] Access to that level of information at a glance allows the agency and the general public to see how the agency is performing in key areas.

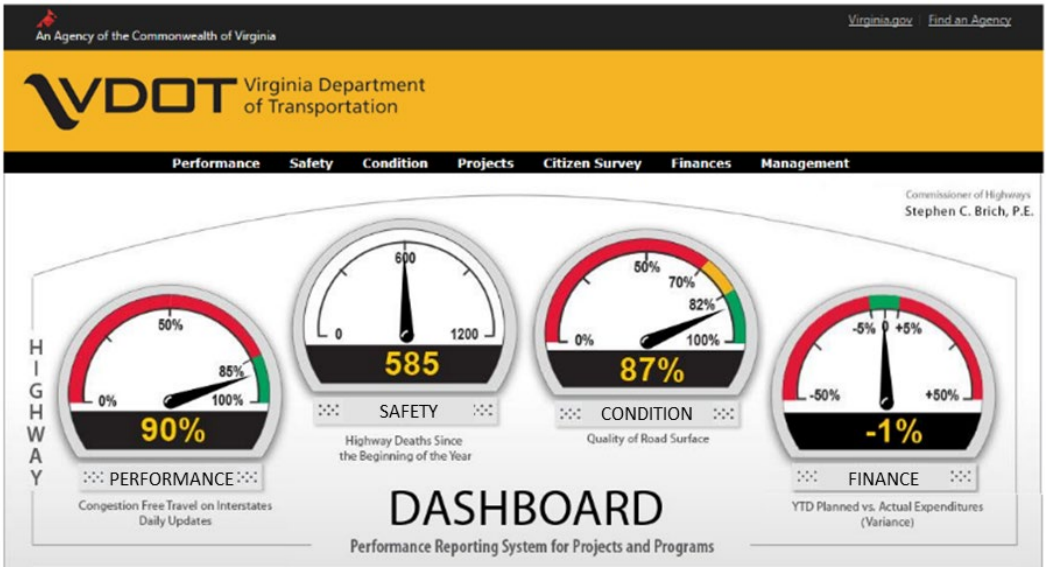



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**Figure 7. Screenshot. VDOT performance measurement dashboard.[18]**

Interviews conducted for this study offer additional insights into TMS assessment as TMS assessment relates to performance measurement. These findings are summarized in the following sections.

### Organization and Workforce

The New Jersey DOT (NJDOT) *Transportation Systems Management* (*TSM) Procedure Manual* covers NJDOT's organizational structure, the TSM organizational structure, and administrative procedures in addition to technical topics such as design, installation, operations, and maintenance of the department's ITS assets.[19] Design details are provided for many ITS subsystems and components, such as DMS systems and variable speed limit systems. The

manual documents many of NJDOT's processes and procedures related to ITS and references several other documents, such as the New Jersey *ITS Strategic Plan* and the *New Jersey Statewide Intelligent Transportation System (ITS) Architecture*.[20,21]

Interviews conducted for this study offer additional insights into TMS assessment as TMS assessment relates to organization and work force. These findings are summarized in the following sections.

### Culture

The Delaware Valley Regional Planning Commission has a Transportation Operations Task Force that meets quarterly and is composed of technical staff representatives or champions from more than 35 regional stakeholders.[22] This task force is an information-sharing forum for ITS deployment and regional and Federal initiatives. The representatives, as champions, are able to work with other stakeholders to advance ITS in the region.

Interviews conducted for this study offer additional insights into TMS assessment as TMS assessment relates to culture. These findings are summarized in the following sections.

### Collaboration

As an example of agency collaboration, Transportation Operations Coordinating Committee (TRANSCOM℠), a coalition of 16 transportation and public-safety agencies, makes real-time event information and travel time data provided by TRANSCOM member agencies available to the public as a data feed.[23] Several member agencies are New York State DOT, New York City DOT, NJDOT, Connecticut DOT, the Port Authority of New York and New Jersey, and the Metropolitan Transportation Authority. This provision of free information is a valuable tool for researchers, media, the public, and commercial vendors who can develop applications with this information.

Interviews conducted for this study offer additional insights into TMS assessment as TMS assessment relates to collaboration. These findings are summarized in the following sections.

## GAPS IN PRACTICE

This section discusses the gaps between the agency practices described in the previous sections and a comprehensive TMS assessment program. This section discusses these gaps in the same framework as the following elements:

- Business process.
- Systems and technology.
- Performance measurement.
- Organization and workforce.
- Culture.
- Collaboration.

## ISSUES TO CONSIDER WHEN DETERMINING CAPABILITIES

This section discusses key issues to consider when assessing TMS capabilities. These issues are discussed in the following categories:

- TMS day-to-day operations.
- Maintenance, repairs, and asset management.
- Operation (e.g., center and performance monitoring, evaluation, and reporting) and active management.
- IT, security, emergencies, and support of other systems (e.g., remote operations).
- Staffing TMSs (e.g., plans, policies, resources, scheduling, and contractors).
- Policies, procedures, and tools to support managing and operating TMS.
- TMS plans, requirements, and resources inclusion in agency or TSMO policies, programs, plans, initiatives, services, or efforts.
- Planning, design, development, and implementation of TMS.
- Planning and plans for an agency's next generation of TMS or improvements.

Agencies should consider all dimensions of the CMF, including the two new dimensions reflected at the end of table 6.[6]

**Table 6. CMF dimensions.[6]**

| Dimensions or Process Areas | What Is It? |
|---|---|
| Business processes | Creating plans, programs, and budgets |
| Systems and technologies | Establishing building systems approach |
| Performance measurement | Using performance measures |
| Workforce | Improving the capability of the workforce |
| Culture | Changing culture and building champions |
| Collaboration | Improving working relationships |
| Management and operations | Managing and operating daily |
| Maintenance and repair | Conducting daily maintenance and repairs |

Agencies should consider the following questions before assessing TMSs:

- What processes will be followed to assess and document results?
- Who should be included in the process or provide reviews?
- What data and information may need to be collected or compiled?

- Has the agency reviewed FHWA CMF and tools (e.g., TSMO, traffic management, ATM) and agreed on a process to follow?[3]

- What resources might the agency need to do the following actions:

    - Prepare for and manage the assessment.
    - Compile data and information needed.
    - Conduct analyses required.
    - Facilitate stakeholder involvement or reviews.
    - Compile results, identify areas for improvement, and create an action plan.

- Has the agency identified TMS-specific topics to include in the assessment:

    - Topics not included in the current framework and tool?
    - Information specific to each TMS topic compiled to include in the assessment?
    - TMS topics incorporated and examples and information provided to support the assessment of the topic?
    - Data and information compiled for topics to be included in the assessment of each process?

Agencies should consider the following key issues when assessing TMSs:

- Day-to-day management and operation.
- Active management cycle.
- Day-to-day maintenance and repair.
- Management, maintenance, and procurement of the following items:

    - Software.
    - Data.
    - IT and TMC technologies.
    - Assets.
    - Staffing.
    - Management of TMS assets and resources.

Agencies should consider the following questions when assessing TMS performance:

- What goals, objectives, or questions need to be addressed or answered?
- What measures are needed to support the assessment?
- Are these measures directly or indirectly produced by available data and information?
- What are the data the TMS needs to collect, use, or make available to support the desired assessment procedure in the future?
- Does the agency have the resources to collect, compile, and manage the desired data and information?
- Are the TMS performance measures and supporting data elements integrated into TSMO planning, programs, and agency strategic plans?

## LEVERAGING THE TRANSPORTATION SYSTEMS MANAGEMENT AND OPERATIONS PROGRAM

Identifying what elements of a TMS or TSMO program may already have information to support the assessment (e.g., goals, performance measures, and performance; condition of assets; staffing needs and plans; strategic or multiyear plan of TMS improvements; and the monitoring and reporting of TMS performance or dashboards) is helpful. TMS or TSMO plans include strategic goals and objectives that can be pulled into the TMS assessment goals.

As an example, California's has the following five strategic goals from its TSMO plan:[24]

- Safety: Reduce fatalities and injuries on the transportation system.
- Efficiency: Enhance system reliability for all modes and users by minimizing the impacts of travel disruptions.
- Climate and environment: Reduce the negative environmental impacts of the transportation system.
- Collaboration and partnerships: Proactively manage and operate an integrated transportation system through internal collaboration and multijurisdictional coordination among various transportation disciplines and partner agencies.
- Excellence: Establish and ensure the availability of expert staff for TSMO, reliable real-time data sources, and clear performance measures.

Agencies may want to look at TSMO strategies and the systems that support them. Some of the following strategies apply:

- Integrated corridor management.
- TIM.
- ATM strategies:
  - Part-time shoulder use.
  - Dynamic lane management.
  - Variable speed limits.
  - Queue warning adaptive ramp metering.
  - Adaptive traffic signal control.
  - Reversible lanes.
- Active parking management strategies.
- Active demand management strategies.

## APPENDIX A. EXAMPLE REPORTS AND DASHBOARDS

This appendix includes examples of reports and dashboards currently used by different agencies to represent how different agencies measure and provide reporting related to TMS capabilities and performance. Table 7 and table 8 depict examples of the PennDOT dashboard.[25]

**Table 7. PennDOT statewide dashboard.[25]**

| Device | Total Device (h) | Total Downtime (h) | Uptime Percent Target | Percent Uptime |
|---|---|---|---|---|
| CCTV | 742,800 | 18,112 | 97.4 | 97.6 |
| Permanent DMS | 365,760 | 7,851 | 97.3 | 97.9 |
| Semipermanent DMS | 49,680 | 973 | 97.1 | 98.0 |
| HAR | 85,680 | 2,781 | 97.0 | 96.8 |
| All devices | 836,400 | 29,716 | 97.1 | 96.4 |

HAR = highway advisory radio.

**Table 8. PennDOT district dashboard.[25]**

| Device | Total Device (h) | Total Downtime (h) | Uptime Percent Target | Percent Uptime |
|---|---|---|---|---|
| CCTV | 316,800 | 10,800 | 98.0 | 96.6 |
| Permanent DMS | 123,840 | 3,600 | 98.0 | 97.1 |
| Semipermanent DMS | 5,760 | 0 | 98.0 | 100.0 |
| HAR | 0 | 0 | 0.0 | 0.0 |
| All devices | 446,400 | 14,400 | 98.0 | 96.8 |

Figure 8 displays a screenshot of the Georgia Department of Transportation (GDOT) dashboard.[26]

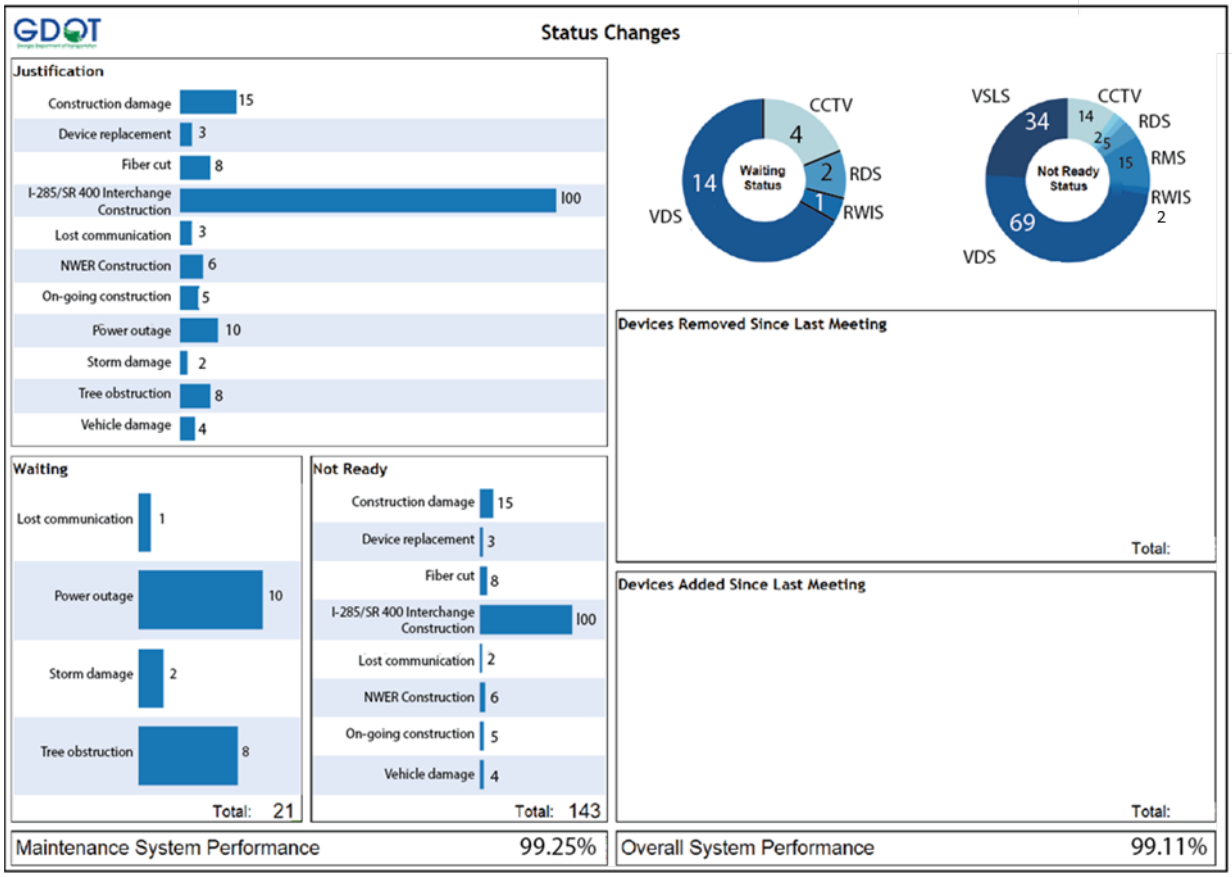




**Figure 8. Screenshot. GDOT dashboard.[26]**

Table 9 describes TMS unit cost and table 10 describes the California DOT (Caltrans) asset condition information. As of the *2019 State Highway System Management Plan*, 19,853 TMS units existed.[27]

**Table 9. Caltrans TMS unit cost.[27]**

| TMS Unit Cost (Poor to Good Cost) | Good Percent | Fair Percent | Poor Percent |
|---|---|---|---|
| $158,871* | 67 | — | 33 |

*Support costs included.
—No data available.

**Table 10. Caltrans TMS unit's condition.[27]**

| Condition | Good | Poor | Poor | Poor |
|---|---|---|---|---|
| Is the unit within expected lifecycle? | Yes | No | Yes | No |
| Is the unit consistently functionally available? | Yes | Yes | No | No |

The overall goal is to bring 90 percent of TMS units in good condition by end of year 2027, both functionally available and within the expected lifecycle. To reduce this number to 10 percent in poor condition by 2027 will require approximately $2.4 billion.[27] Table 11 describes the Minnesota DOT (MnDOT) asset condition, targets, and investments.[28]

**Table 11. MnDOT's asset condition, targets, and investments.[28]**

| System | 2017 Condition (Percent Approaching or Beyond Useful Life*) | Targets (Percent Approaching or Beyond Useful Life*) | Investment Required to Achieve Targets |
|---|---|---|---|
| Rural intersection conflict warning systems | 0 | <=6 | $6.1 million |
| RWIS sites | 0 | <=2 | $8.0 million |
| Automatic traffic recorders and weigh-in-motion system sites | No inspection criteria | <=10 | $11.1 million |
| Road closure systems | 0 | <=10 | $0.8 million |
| Total | — | — | $26.0 million |

*Approaching or beyond useful life is a combination of poor/nonfunction and very poor/fail/critical.
—Not applicable.

## APPENDIX B. LITERATURE REVIEWED FOR THIS PROJECT

Table 12 provides a summary of literature the research team reviewed for this project.

**Table 12. Summary of literature reviewed for the project.**

| No. | Document | Source | Location |
|---|---|---|---|
| 1 | What is What is Transportation Systems Management and Operations (TSMO)?[29] | FHWA | https://ops.fhwa.dot.gov/tsmo/index.htm#q1 |
| 2 | *TMC Performance Monitoring, Evaluation and Reporting Handbook*[30] | National Operations Center of Excellence (NOCoE) | https://transportationops.org/traffic-management-systems-and-centers/resources-traffic-management-system-and-centers/monitoring-evaluating-and-reporting-tms-performance/Handbook |
| 3 | Business Process Frameworks for Transportation Operations[31] | FHWA | https://ops.fhwa.dot.gov/tsmoframeworktool/using_frameworks.htm |
| 4 | *NOCoE Asset Management: Virtual Peer Exchange Proceeding Report*[32] | NOCoE | https://transops.s3.amazonaws.com/uploaded_files/NOCoE_Asset%20Management%20Peer%20Exchange%20Report%202021_0.pdf |
| 5 | *Managing Traffic Management Systems Assets*[33] | FHWA | Not available online |
| 6 | Completed Projects: Performance Measures and Health Index of Intelligent Transportation System (ITS) Assets[12] | FHWA | https://tmcpfs.ops.fhwa.dot.gov/projects/measureshealth.htm |
| 7 | *Review of Traffic Management Systems—Current Practice*[7] | FHWA | https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-23-051.pdf |
| 8 | *Applying Transportation Asset Management to Intelligent Transportation Systems Assets: A Primer*[34] | FHWA | https://ops.fhwa.dot.gov/publications/fhwahop20047/fhwahop20047.pdf |
| 9 | *IT Asset Management: It's All About Process*[35] | Gartner® Inc. | https://s0.whitepages.com.au/1682a770-80a7-4e17-b04c-85def4aa2158/gartner-australasia-pty-ltd-document.pdf |

| No. | Document | Source | Location |
|---|---|---|---|
| 10 | *Transportation Management Center Performance Dashboards*[36] | FHWA | https://ops.fhwa.dot.gov/publications/fhwahop20032/fhwa20032.pdf |
| 11 | Welcome to Business Process Frameworks for Transportation Operations[10] | FHWA | https://ops.fhwa.dot.gov/tsmoframeworktool/index.htm |
| 12 | Business Process Frameworks for Transportation Operations: Capability Maturity Frameworks Overview[3] | FHWA | https://ops.fhwa.dot.gov/tsmoframeworktool/cmf_overview.htm |
| 13 | Business Process Frameworks for Transportation Operations: Using the Frameworks[37] | FHWA | https://ops.fhwa.dot.gov/tsmoframeworktool/using_frameworks.htm |
| 14 | Business Process Frameworks for Transportation Operations: Traffic Management Capability Maturity Framework Tool[11] | FHWA | https://ops.fhwa.dot.gov/tsmoframeworktool/available_frameworks/traffic.htm |
| 15 | Traffic Management Capability Maturity Framework: Factsheet[38] | FHWA | https://ops.fhwa.dot.gov/publications/fhwahop16026/index.htm |
| 16 | Resources to Support Traffic Management Capability Maturity Framework Users[39] | FHWA | https://ops.fhwa.dot.gov/tsmoframeworktool/resources/tm_cmf_res/index.htm |
| 17 | *Transportation Systems Management and Operations (TSMO) Program Plan for Pennsylvania*[40] | PennDOT | https://www.penndot.gov/ProjectAndPrograms/operations/Documents/PA%20TSMO%20Program%20Plan.pdf |
| 18 | Traffic Operation Assessment Systems Tool (TOAST)[16] | ODOT | https://www.transportation.ohio.gov/wps/portal/gov/odot/working/data-tools/resources/toast |
| 19 | SunGuide Software[17] | FDOT | https://www.fdot.gov/traffic/its/projects-arch/sunguide.shtm |
| 20 | VDOT Dashboard: VDOT's Performance Reporting Program[18] | VDOT | http://dashboard.virginiadot.org/ |
| 21 | *TSM Procedures Manual*[19] | NJDOT | https://www.state.nj.us/transportation/eng/elec/ITS/pdf/TSMProceduresManual.pdf |
| 22 | Transportation Operations Task Force[22] | DVRPC | https://www.dvrpc.org/Committees/TOTF/ |
| 23 | Traffic Management & Intelligent Transportation System[23] | TRANSCOM | https://www.xcm.org/home |

| No. | Document | Source | Location |
|---|---|---|---|
| 24 | *Summary State DOT Practices for Developing and Implementing TSMO Plans*[41] | National Cooperative Highway Research Program | http://nap.edu/26206 |
| 25 | Business Process Frameworks for Transportation Operations: Traffic Signal Management Capability Maturity Framework Tool[42] | FHWA | https://ops.fhwa.dot.gov/tsmoframeworktool/available_frameworks/traffic_signal.htm |
| 26 | Traffic Signal Management Capability Maturity Framework: Factsheet[43] | FHWA | https://ops.fhwa.dot.gov/publications/fhwahop16028/index.htm |
| 27 | *Using Capability Maturity Frameworks for Transportation System Management and Operations Program Advancement: Case Studies and Lessons Learned* (Chapter 5. Traffic Management Capability Maturity Framework)[44] | FHWA | https://ops.fhwa.dot.gov/publications/fhwahop19011/ch5.htm |
| 28 | *Using Capability Maturity Frameworks for Transportation System Management and Operations Program Advancement: Case Studies and Lessons Learned* (Chapter 3. Traffic Signal System Capability Maturity Framework)[44] | FHWA | https://ops.fhwa.dot.gov/publications/fhwahop19011/ch3.htm |
| 29 | *Transportation Systems Management and Operations (TSMO) Implementation and Strategic Plan*[45] | Michigan DOT (MDOT) | https://www.michigan.gov/documents/mdot/MDOT_TSMO_Imp_Strat_Plan_Version1_2-2-18_612971_7.pdf |
| 30 | ATMS Infrastructure Alignment Project[46] | NOCoE | https://transportationops.org/case-studies/atms-infrastructure-alignment-project |

| No. | Document | Source | Location |
|---|---|---|---|
| 31 | *TMC Pooled Fund Study Completed Projects: TMC Performance Monitoring, Evaluation, and Reporting Handbook*[47] | FHWA | https://tmcpfs.ops.fhwa.dot.gov/projects/tmcpmerhdbk.htm |
| 32 | *Integrating Asset Management Into the Transportation Planning Process: A Transportation Asset Management Expert Task Group*[48] | FHWA and AASHTO | http://onlinepubs.trb.org/onlinepubs/conferences/2016/AssetMgt/76.LauraMester.pdf |
| 33 | *Integrating Asset Management into the Transportation Planning Process: A Briefing Paper*[49] | AASHTO | https://www.tam-portal.com/wp-content/uploads/sites/12/2016/01/AM-Planning-Process.pdf |

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