Inventorying, Documenting, and Configuring Traffic Management System Assets and Resources—Current Practices

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FOREWORD

State and local transportation agencies plan, design, implement, manage, and maintain traffic management systems (TMSs) to help improve the safety and mobility of the traveling public. A TMS is a complex, integrated blend of hardware, software, processes, and people performing a range of functions and actions. TMS assets are the physical elements, such as the hardware, software, infrastructure, or equipment, that agencies can manage to support reliable operation of the TMS.

To improve performance and control costs, agencies are realizing the value of inventorying, documenting, and configuring their TMS assets and resources. This report presents concepts, processes, activities, tools, challenges, practices, and benefits for agencies to consider in support of inventorying, documenting, and configuring TMS assets and resources. By documenting, inventorying, and configuring assets and resources, agencies may enhance the day-to-day management and operation of their TMSs. Agencies may also benefit from incorporating information about these assets and resources into planning for TMS improvements, pursuing the next generation of TMSs, and other agency processes. 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 who are responsible for or support managing and operating TMSs.

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

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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 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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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
Caltrans	California Department of Transportation
CCTV	closed-circuit television
CFR	Code of Federal Regulations
CM	configuration management
CSA	configuration status accounting
DMS	dynamic message sign
DOT	department of transportation
EAM	enterprise asset management
FHWA	Federal Highway Administration
GIS	geographic information system
IT	information technology
ITS	intelligent transportation systems
KITO	Kansas Information Technology Office
LCP	lifecycle planning
MARC	Mid-America Regional Council
MDOT SHA	Maryland Department of Transportation State Highway Administration
NDOT	Nevada Department of Transportation
ODOT	Oregon Department of Transportation
QA	quality assurance
QC	quality control
RWIS	road weather information system
SLA	service-level agreement
TAM	transportation asset management
TAMP	transportation asset management plan
TDOT	Tennessee Department of Transportation
TMC	traffic management center
TMS	traffic management system
TSMO	transportation systems management and operations
VDOT	Virginia Department of Transportation
WIM	weigh-in-motion

CHAPTER 1. INTRODUCTION

As State and local agencies look for ways to safely improve the mobility of the traveling public, they continue to design and implement traffic management systems (TMSs) to help them achieve these goals. A TMS is composed of a complex, integrated blend of hardware, software, processes, and people performing a range of functions and actions. TMS assets are the physical elements that can be managed to support the reliable operation of the TMS, including the hardware, software, infrastructure, or equipment.

To help better manage these new assets and resources, agencies have realized the importance of inventorying, documenting, and configuring TMS assets. The purpose of this report is to present the concepts of inventorying, documenting, and configuring TMS assets and the benefits these actions provide to agencies. The report also documents the practices, challenges, and trends as they relate to inventorying, documenting, and configuring TMS assets and resources.

This document highlights the issues to consider and potential value of developing an inventory, documenting, and configuring TMS assets and resources. This report addresses the issues to consider when using this inventory and allowing others to access and use this information. The report also explores how this information may be considered in the other processes, actions, and tasks that may be carried out in support of managing and operating a TMS.

This report aims to accomplish the following:

- Provide an overview of current agency practices for inventorying, documenting, and configuring all the assets used to manage a TMS.
- Describe challenges agencies face in inventorying, documenting, and configuring TMS assets.
- Identify issues to consider when managing information on TMS assets and resources and allowing others to access and use the information.
- Highlight issues and opportunities to consider how the inventory of TMS assets and resources can be integrated into the day-to-day management and operation of a TMS.

This chapter provides a background on managing TMS assets; the benefits of inventorying, documenting, and configuring assets and resources; who may benefit from reading this document; and the overall organization of the report.

MANAGING TMS ASSETS AND RESOURCES

The process of managing TMS assets is similar to transportation infrastructure asset management, but with some differences. Transportation infrastructure asset management is defined in 23 Code of Federal Regulations (CFR) § 515.5, as follows (CFR 2022):

> A strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on engineering and economic analysis based on quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at minimum practicable cost.

Transportation infrastructure asset management provides a broad approach on how agencies can manage their assets cost effectively over a long period. Managing assets focuses on the ongoing reliability and performance of each asset. Asset management has traditionally been associated with bridges, pavements, and other roadway infrastructure elements.

The core principles of transportation asset management are as follows (Federal Highway Administration (FHWA) 2017):

- Policy-driven: Resource allocation decisions are based on a well-defined set of policy goals and objectives.
- Performance-based: Policy objectives are translated into system performance measures used for both day-to-day and strategic management.
- Analysis of options and trade-offs: Fund allocation decisions within and across different types of investments, such as preventive maintenance versus rehabilitation, are based on analysis of how different allocations will impact the achievement of relevant policy objectives.
- Quality information-based decisions: The merits of different options are evaluated using credible and current data, with respect to an agency's policy goals.
- Condition monitoring supports accountability and feedback: Performance results are monitored and reported for both impacts and effectiveness.

Asset management applied to TMSs can adapt various approaches, tools, and techniques recommended for managing transportation infrastructure assets. However, TMSs differ from traditional transportation infrastructure in several aspects. TMS operations include physical assets that require maintenance, repair, and replacement, but equipment reliability is just one factor influencing their performance. Additionally, the systems connecting, controlling, and managing TMS assets, as well as the personnel and policies impacting the maintenance, operations, and repair of these assets and resources play roles in ensuring optimal TMS performance.

Managing TMS assets offers benefits that contribute to the overall performance of the system. These benefits include the preservation of asset health, ensuring maximum device availability, rapidly identifying and resolving performance issues, and optimizing the use of assets for TMS management and operations. As TMS assets share similarities with information technology (IT) devices, they possess unique lifecycles and depreciation rates that differ from traditional highway infrastructure assets. By recognizing and addressing these differences, agencies can successfully manage TMS assets to achieve optimal performance and cost effectiveness throughout their lifecycles (FHWA forthcoming).

A TMS inventory also supports various processes in the lifecycle of a TMS. By connecting the inventory to the TMS operations, agencies can effectively monitor and manage the performance of individual assets and troubleshoot issues. The integration of inventory data into the daily operations of a TMS allows for more efficient resource allocation, minimizes system downtime, and enhances system reliability. A well-maintained inventory also supports long-term planning and budgeting, as it provides valuable insights into asset lifecycles, depreciation rates, and anticipated replacement costs. The inventory supports day-to-day management and operation of the TMS and contributes to a more sustainable and cost-effective TMS.

Many agencies are developing and using inventories, which are curated lists of TMS assets and resources that an agency chooses to document, track, monitor, and manage. Examples of TMS assets include closed-circuit television (CCTV) cameras; changeable message signs; vehicle detection devices and other field devices; and various subsystems and components, such as cabinets, controllers, and telecommunication subsystems. (More examples are provided in chapter 3.) Resources that support the operation and management of TMS assets include policies, procedures, project designs, and operations manuals. By incorporating these resources into an inventory, agencies can effectively organize and manage their TMS assets and related information, enabling efficient decisionmaking throughout the lifecycle of their TMS.

Building on the foundation of a TMS asset inventory, agencies can engage in a range of activities to effectively manage and maintain TMS assets throughout their lifecycles. These activities can help optimize the performance of TMS assets and enable efficient resource allocation. The following list outlines key activities involved in managing a TMS asset inventory (Weatherford et al. 2024):

- TMS asset identification—Assets are classified and grouped by function.
- TMS asset inventory—Asset information, such as asset type, make, model, and serial number, is entered into tracking tools, such as spreadsheets, or into more sophisticated inventory products.
- TMS asset condition— Asset condition is usually classified in terms of good, fair, or poor.
- TMS asset maintenance—Asset maintenance information is important for confirming recurring device issues and problems, primarily in particular assets; agencies can use this information to discontinue use of the particular device or technology and use a replacement technology.

- TMS asset spares and resources—Many agencies keep device spare parts available and track them to ensure urgent repairs can be performed immediately or in a timely fashion.

- TMS asset configuration—Agencies include configuration information as part of their inventories.

- Monitoring asset conditions—Continuous monitoring and determining the condition of the asset can prompt initiation of other actions, such as asset maintenance and repair.

- Evaluating asset conditions—Evaluating asset conditions, in addition to monitoring, can lead to eventual replacement of the asset.

- Reporting on asset conditions—Many inventorying tools can produce reports, such as device availability and percent of device uptime.

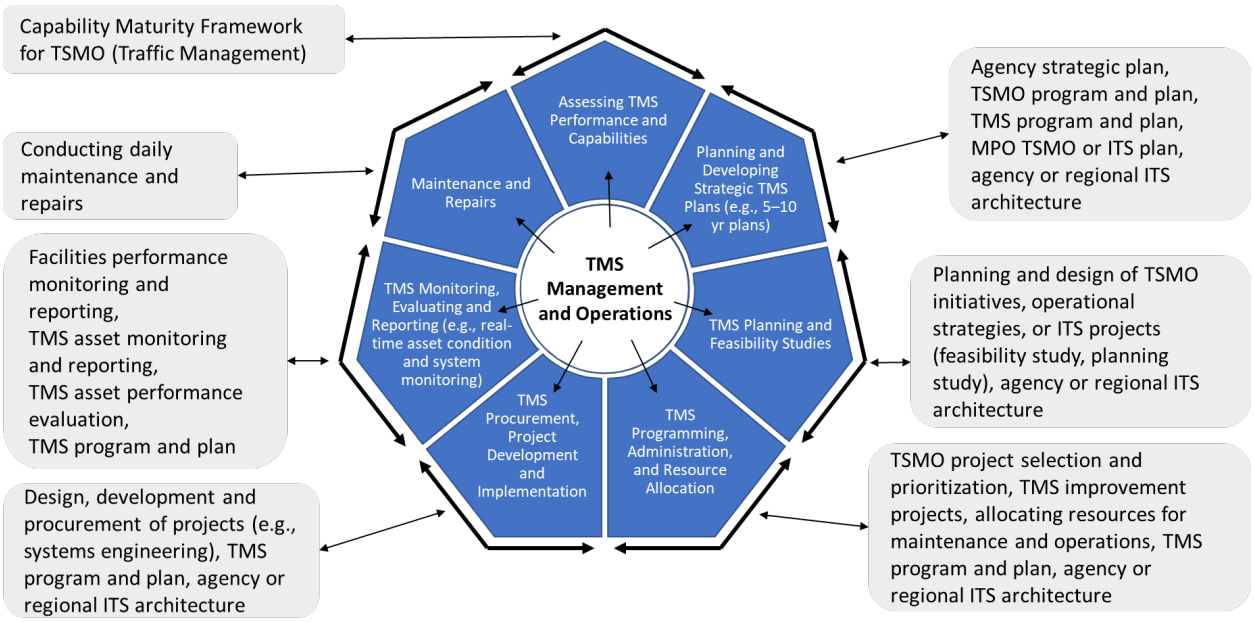
Studies and reports have documented efforts to manage traffic signals, intelligent transportation system (ITS) projects, and transportation systems management and operations (TSMO) programs. The FHWA report *Managing Traffic Management Systems Assets* introduces activities, practices, and resources for managing TMS assets. The report highlights that important activities for agencies to consider include TMS asset identification, classification, and inventorying; TMS asset spare management; TMS asset configuration management (CM); and TMS asset monitoring, evaluation, and reporting (Weatherford et al. 2024).

The report *Elements of a Comprehensive Signals Asset Management System* provides information to assist agencies with managing traffic signal assets. Research presented in this report indicates the asset inventory should consider including asset location, age, and condition (Harrison et al. 2004). Information on the configuration, maintenance, and repair of these systems supports improved TMS performance. *Handbook for Including Ancillary Assets in Transportation Asset Management Programs* helps highway asset owners and maintenance personnel establish a prioritized approach to adding assets other than pavement and bridges (e.g., signals, signs, and raised pavement markings) to an asset management program (Allen et al. 2019).

An accurate and regularly updated inventory of TMS assets—that contains conditions, maintenance, and repair histories—is beneficial for effective decisionmaking within an agency. The anticipated outcome of monitoring, evaluating, and reporting on TMS assets is having the right information for different audiences to support managing the TMS and TMS planning. These activities, practices, and resources aim to facilitate informed decisionmaking that maintains and improves TMS assets while using a TMS effectively to meet the agency's objectives.

Figure 1 is a conceptual illustration of agency TMS processes and plans and the relationships among them, demonstrating how they support the management and operation of the system. Managing TMS assets and an asset inventory is closely related to many of these plans and processes, primarily by developing and managing reliable and actionable data about the TMS assets.

The primary input for managing TMS assets is in the processes for TMS monitoring, evaluating, and reporting. The result of effectively managing TMS assets is an accurate understanding of an agency's TMS asset inventory, condition, reporting, and needs. The process of monitoring, evaluating, and reporting on the condition of assets may inform the TMS planning process and plans. The information on the condition of these assets may also support other processes and decisions that occur throughout the lifecycle of a TMS.



Source: FHWA.

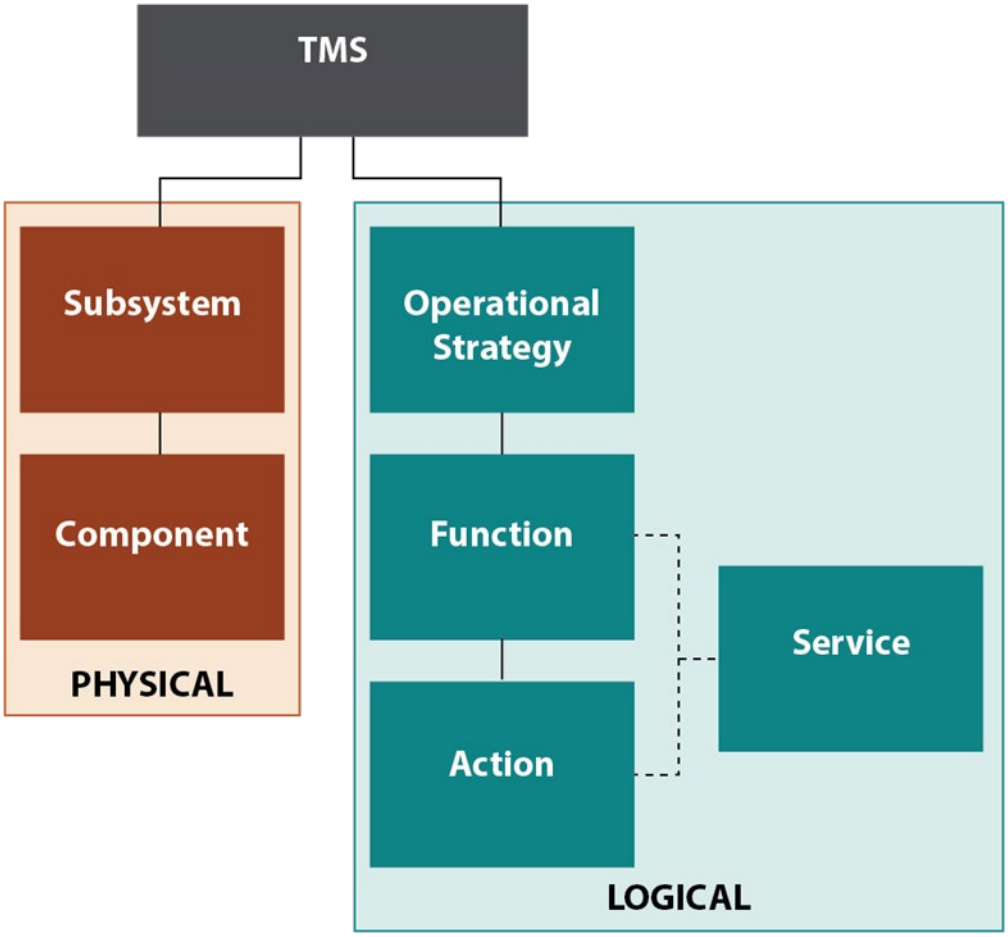
Figure 1. Diagram. TMS and agency processes (Weatherford et al. 2024).

TMS OVERVIEW

A TMS is a complex integration of hardware, software, processes, and people performing a range of functions and actions. TMSs are focused on improving the efficiency, safety, and predictability of travel on the surface transportation network. TMSs have been deployed to meet the ever-increasing transportation needs of society.

Demands on a TMS have evolved from solely reporting travel times to a wider range of functions, actions, and services. TMSs typically provide functions, actions, and services that support sharing information on travel conditions, detecting incidents, managing the use of operational strategies in response to changing conditions, and improving safety and travel on the surface transportation network. TMSs are complex systems that combine field equipment, operations personnel, communications, IT, information sharing, and use of operational strategies to meet agencies' missions.

The more complex TMSs are composed of multiple subsystems. A subsystem is a group of self-contained, interactive components that support one or more operational strategies as a part of a TMS. For example, a statewide TMS may be composed of multiple smaller subsystems working together to meet agency goals and implement operational strategies. The design or structure of a TMS can be broken down into its physical elements and its logical elements. The physical elements are the subsystem and the components. The logical elements are the operational strategies, functions, actions, and services. Figure 2 shows the TMS structure.



Source: FHWA.

Figure 2. Diagram. Basic TMS structure (Kuciemba et al. 2023).

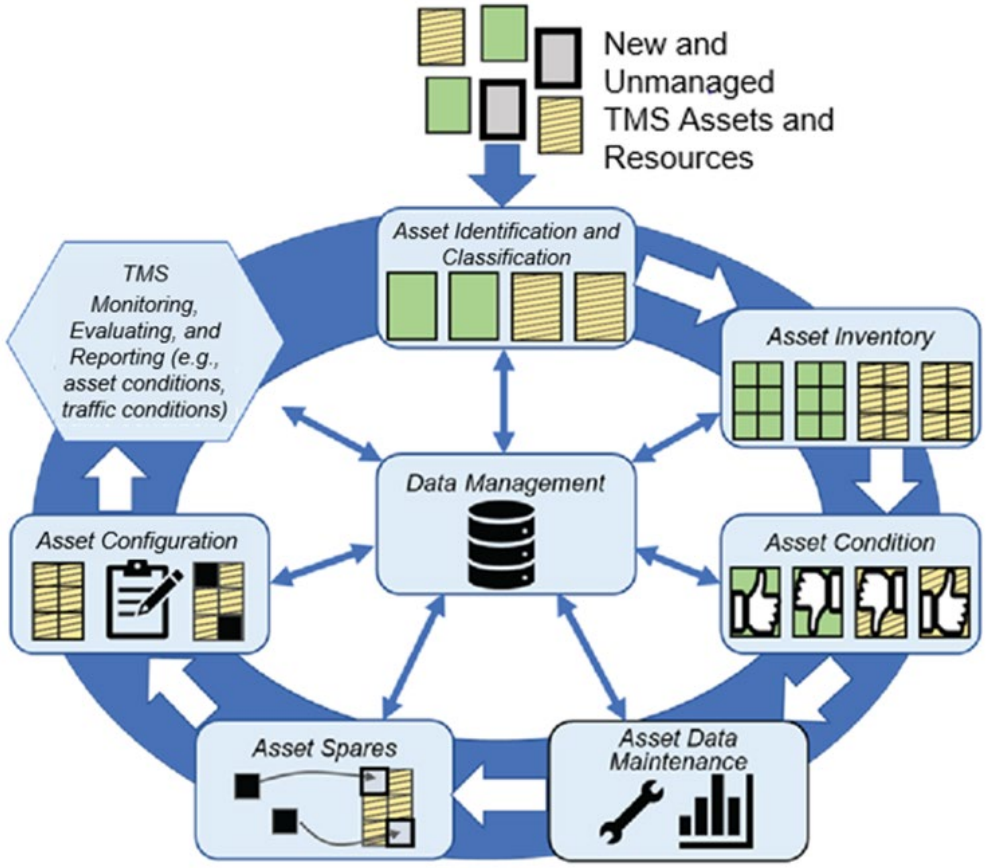
Process of Managing TMS Assets

Figure 3 illustrates a range of activities an agency considers in support of managing its TMS assets. The range of activities includes the following (Weatherford et al. 2024):

- Preparing to manage TMS assets.
- Managing TMS asset data, which includes TMS asset identification, classification, and inventorying.

- Maintaining TMS asset data, which includes TMS asset condition rating, data maintenance, asset spare management, and managing the configuration of assets.

- Monitoring, evaluating, and reporting on TMS assets.



Source: FHWA.

Figure 3. Diagram. Activities to manage TMS assets (Weatherford et al. 2024).

Embedded within the activities to manage TMS assets are three important topics, as follows:

- An inventory of TMS assets and resources.
- A process to document TMS asset information.
- A CM process for TMS assets, TMS asset inventory, and TMS asset documentation.

By regularly inventorying and monitoring TMS asset conditions, agencies can quickly identify, detect, and resolve device issues, improving the ability to effectively manage and operate a TMS. This active management and operation of a TMS also involves using the functions, actions, and information compiled to support monitoring the condition of assets and the collection and storage of relevant data. The next section introduces the concepts of inventorying, documenting,

and configuring TMS assets, highlighting the significance of these processes in the overall management of TMS assets and their contribution to agency decisionmaking.

TMS INVENTORYING, DOCUMENTING, AND CONFIGURING

Inventorying is the process of compiling a list of all assets and resources. The information to include in an inventory varies for different TMS subsystems and TMS components. As an example, a ramp metering subsystem inventory may include quantities and locations of the ramp meters in the subsystem. The inventory for individual ramp meter components may include more detailed information, such as make, model, or warranty information.

An inventory of TMS assets helps agencies keep track of, monitor, and use inventory information to manage and operate assets effectively. An agency can use inventory information to support the following:

- Planning TMS improvements.
- Programming initiatives or activities impacting the TMS.
- Operating the TMS day-to-day.
- Performing ongoing maintenance and repairs.
- Managing TMS assets.
- Procuring individual TMS elements.

When agencies have a clear idea of the number, location, and condition of assets at their disposal, they are better able to actively manage and maintain the assets on a day-to-day basis. Assets can be scheduled for routine preventive maintenance, or work orders can be issued to repair or replace nonfunctional devices. Inventorying devices and using the information not only supports activities related to managing assets but also activities related to actively managing and operating a TMS. Chapter 3 provides more information on inventorying TMS assets.

Documenting assets is the process of capturing and preserving information about TMS assets and resources. The objective is to give a comprehensive picture of these assets and resources. This information may include the dates of preventive maintenance inspections; work orders; maintenance or repair records; and device documentation, such as manuals, warranties, and specifications. The documentation can reveal patterns in device performance and verify information about each device, such as its age, model, software type and version, and communication method. This information can assist agencies in making decisions about maintaining, repairing, or replacing a device. Chapter 4 provides further information about documenting TMS assets.

CM is the application of processes and procedures to control system changes. TMSs, due to the number of subsystems and components involved, are in states of constant change. Agencies are constantly removing or replacing devices as part of maintenance or replacement efforts. CM systematically handles changes to subsystems and components, so the TMS maintains integrity over time. Chapter 5 provides more information on the entire CM process.

Inventorying, documenting, and configuring are three interdependent activities for managing a TMS. For example, an agency that installs CCTV cameras on its transportation network can either add the new cameras to an existing inventory or initiate an inventory if the agency does not have an inventory. The inventory may include the make, model, and serial number of the cameras. The agency can expand the inventory by adding preventive maintenance schedules for the new devices. By documenting changes to individual camera settings as part of the CM process, agencies can enhance situational awareness of their assets, resulting in improved management of the assets.

The subsequent chapters provide more detailed information about inventorying, documenting, and configuring TMSs. The next section discusses challenges and opportunities for TMS use.

TMS CHALLENGES AND OPPORTUNITIES

Effective management of TMS assets, including creating and maintaining an inventory, can be challenging; however, the practice presents many opportunities for improvement. In planning to implement or upgrade TMSs, agencies may encounter various challenges, even while simultaneously discovering new ways to enhance TMS management and operations. By incorporating the use of an inventory, maintaining it, and leveraging the information for other agency processes, agencies can more effectively address challenges and capitalize on the opportunities they offer.

Some of the existing inventory challenges for agencies include the following:

- Initiating the establishment of an inventory of TMS assets and resources.
- Operating and maintaining the TMS components continuously.
- Improving the day-to-day TMS performance.
- Handling the rising costs to operate and maintain the system.
- Managing the demands on staff resources and their ability to operate and maintain the system.

Agencies tend to differ in how they manage their TMS assets and resources, particularly in terms of inventorying. Some agencies have already established an inventory, but they lack a system for maintaining and using this information. For these agencies, the challenge lies in developing and implementing strategies to maintain inventory and effectively using the information collected to manage and operate TMSs or support other processes.

In contrast, other agencies may only have inventory information for some TMS assets and lack complete inventories for all TMS assets. The challenge for many agencies is to determine what items may be appropriate or feasible to include and how to initiate the process of creating an inventory of TMS assets and resources.

Incorporating inventorying practices into the daily operations of an agency requires time and resources. Agencies may need to initiate specific activities and efforts and make changes to effectively implement these practices. For example, agencies may need to assign dedicated staff or contractors to managing and maintaining the inventory. Additionally, training and support may be necessary to ensure staff is equipped with the knowledge and skills to effectively use the

information. The benefits of having a sufficient and up-to-date inventory of TMS assets and resources can be significant—and can inform agency decisionmaking and planning activities.

If an agency does not update its TMS asset inventory during asset maintenance and repair, this practice can lead to the collection of outdated or incomplete information. To keep the inventory current, agencies can make changes in near realtime by documenting any work performed and new assets installed or capturing other information on an asset. Part of the CM process is managing and confirming updates made to the inventory. For example, the CM process may begin to include all possible documentation for any work performed on existing assets or on any new assets implemented—information that is appropriate to include in a TMS inventory.

When agencies replace or decommission devices, they may also need to update inventories by removing old assets and adding new devices. These changes help ensure the inventory remains current and provides a complete history of the devices. Moreover, having current information on the assets and their conditions can be incorporated into other processes to manage and operate the TMS or agency more effectively, ensuring optimal use of resources and timely maintenance.

Agencies may find that figuring out how to plan for system improvements is challenging. Understanding the existing TMS assets and their conditions is beneficial for evaluating, planning, and preparing for improvements. Accessing the information in an inventory of assets that includes asset make, model, and age can also support these efforts.

Any information on TMS assets that is not currently inventoried or documented may be collected and incorporated in an early phase of any planning effort for considering system improvements. Agencies may want to consider opportunities to update inventories and documentation when changes or improvements are made to a TMS. For example, an agency likely adds new devices during a system improvement project. Agencies may include these new devices in the inventory through contract document requirements.

VALUE PROPOSITION OF INVENTORYING, DOCUMENTING, AND CONFIGURING TMS ASSETS AND RESOURCES

The value proposition of inventorying, documenting, and configuring TMS assets lies in the ability of an agency to make informed, strategic decisions that align with goals and objectives. By carefully considering and deciding what to include in the inventory and maintaining up-to-date information, agencies can ensure that their efforts are focused on what truly adds value. This focus can enable the agency to prioritize and allocate resources effectively, enhancing overall TMS management and operation while also improving the efficiency of planning maintenance and procurement processes.

Having an inventory of TMS assets and resources helps agencies understand important information, such as how many devices they have for a specific purpose, the conditions of assets, and their ages. This information can be used to create a preventive maintenance schedule for the assets. The number of assets that need maintenance will impact the amount of effort needed for the task and for all other tasks related to managing and operating TMS assets.

Documenting information about TMS assets, such as the number of device failures over a certain period or the number of maintenance work orders for a specific type of asset, provides situational awareness of potential asset performance or quality issues. With this information, agencies can make informed decisions, such as choosing to use increasingly reliable devices and technologies and discontinuing use of less reliable ones. Realtime notifications of changes in asset condition can also help an agency with realtime maintenance and repair efforts.

One of the values of CM is the historical record created during the configuration process. When a system change is proposed, evaluated, implemented, and documented, any new personnel coming into the process can retrace steps to see the system changes and evolution. Going forward, planning and implementing new system changes can become easier when the processes and final outcomes of prior system changes have been documented.

As shown in figure 1, a variety of existing agency planning processes and activities may impact the capabilities, performance, strategic direction, management, and operation of a TMS. Each of these activities benefits from using and incorporating TMS asset inventory data, condition information, and documentation. TMS asset inventory and condition information are key inputs that support several agency processes, such as planning for and developing plans for TMS improvement projects. When agencies rank and prioritize possible TSMO or TMS improvement projects, the inventory data and condition of TMS assets can inform analysis, planning, and decisionmaking for TSMO programs, initiatives, and projects.

INTENDED AUDIENCE

The intended audience of this report includes representatives from State departments of transportation (DOTs), local agencies, metropolitan planning organizations, regional authorities, toll authorities, and other groups involved with or 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, TMC supervisors, transportation engineers and planners, TMC operators, maintenance personnel, IT staff, the research community, and others with roles in the TMS lifecycle.

An individual's specific roles and responsibilities within a TMSs lifecycle may influence how an audience will use this report, as certain chapters or sections may be more relevant than others. For example, TMC 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 inventorying and documenting assets important. Maintenance personnel may place higher importance on the inventory and documentation information; meanwhile, the research community may want a higher-level understanding of the processes.

This report can help agencies with the following:

- Deciding to create an inventory and determining which assets and resources to include.
- Ensuring the management and regular updating of an inventory to keep it current.
- Learning about methods and tools for inventorying TMS assets and resources.

- Learning approaches to documenting TMS assets and resources.
- Understanding schemes for managing the configuration of TMS assets and resources.
- Identifying opportunities for leveraging TMS asset and resource information to support other processes and plans.
- Managing access and usage of TMS inventory of assets and resources.

REPORT ORGANIZATION

This report identifies current practices related to inventorying, documenting, and configuring TMS assets and resources. This report also explores practices for managing and maintaining information on TMS assets and resources and potential methods for incorporating this information into other planning process or activities. Appendix A provides the literature referenced while preparing this report. The report also includes information gathered from one-on-one interviews with selected agency personnel.

This report includes eight chapters, organized as follows:

- Chapter 1: Introduction. This chapter introduces the purpose and objectives of the report and provides background on TMSs and managing TMS assets and the benefits of inventorying, documenting, and configuring TMS assets and resources.
- Chapter 2: Inventorying, Documenting, and Configuring TMS Assets and Resources. This chapter introduces the three primary topics of this report: inventorying, documenting, and configuring TMS assets and resources. The chapter also touches on the importance of keeping inventory information current. Additionally, the chapter discusses agency motivations for having an asset and resource inventory, the documentation process, and the benefits of CM.
- Chapter 3: Inventorying TMS Assets and Resources. This chapter defines what an inventory is, lists example assets and resources that can be included as part of an inventory, and provides information about tools used in the inventory process. The chapter addresses initiating the inventory effort, the importance of sustaining the effort, and how agencies can integrate inventory information into other processes for the long-term success of TMSs.
- Chapter 4: Documenting TMS Assets and Resources. This chapter provides insights on documenting TMS assets and resources. The chapter also discusses the definition, importance, and benefits of documenting assets and resources. Additionally, the chapter addresses initiating and sustaining documentation as a long-term effort.
- Chapter 5: Configuring TMS Inventory and Resources. This chapter discusses the definition, importance, and benefits of configuring assets and resources. The chapter also discusses initiating the creation of an inventory, sustaining the process, and identifying stakeholders who may participate in these efforts.

- Chapter 6: Managing TMS Inventories and Resources. This chapter discusses current practices, challenges, and opportunities in managing TMS inventory and resources, including how a TMS inventory is managed and used over time.

- Chapter 7: Maintaining TMS Inventories and Resources. This chapter discusses current practices, challenges, and trends in maintaining TMS inventories and resources, including how a TMS inventory is maintained over time.

- Chapter 8: Incorporating TMS Inventory Into TMS Planning. This chapter addresses how agencies can use TMS inventory information as part of the TMS planning effort.

- Appendix A. Literature Review.

- Appendix B. List of Agencies Interviewed.

CHAPTER 2. INVENTORYING, DOCUMENTING, AND CONFIGURING TMS ASSETS AND RESOURCES

This chapter discusses the importance of creating and maintaining an inventory of TMS assets and resources. Additionally, this chapter discusses the importance of introducing processes to update the inventory as soon as possible after device inspections, maintenance, repairs, or replacements. The chapter also discusses agency motivations for having an inventory of TMS assets and resources, and the processes and tasks associated with documenting, configuring, and managing the inventory. Additionally, this chapter discusses the process of enabling others to use this information.

This chapter highlights the importance of both initiating and maintaining an inventory effort. It introduces key issues to consider when inventorying, documenting, and configuring TMS assets and resources. This chapter also explores the role of managing TMS assets in supporting the agency's overall asset management effort. The initial steps of establishing an inventory, documenting assets and resources, and configuring the system are important. Continuing to maintain the inventory, documenting information on assets and resources, and addressing any system changes through CM efforts are equally important.

Storing inventory information on TMS assets in databases or tools enables users to access the information according to their specific needs. To ensure access to this information, storing information on platforms or providing tools to support easy access to relevant users is important. Permission levels can be assigned for each user based on the user's level of access, such as read-only or read-write. This way, the inventory can be configured and documented to support this information being accessed and potentially used in all processes, activities, and related tasks performed during the TMSs lifecycle.

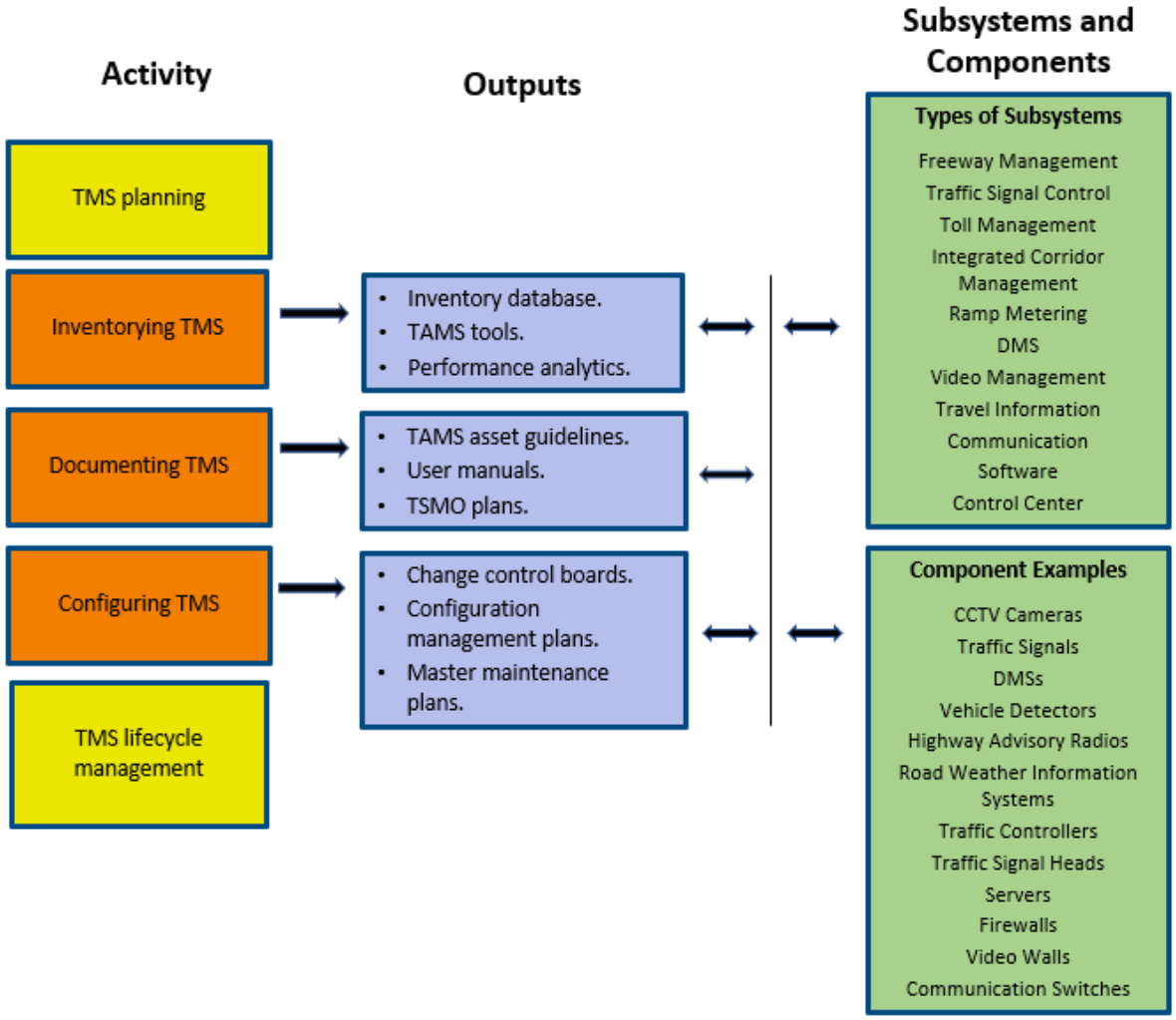
Incorporating the use of inventory information into other agency processes, such as TSMO planning or TSMO project development, allows for better coordination and decisionmaking. Monitoring the condition of assets may support the active management and operations of a TMS. Information about the asset's condition can also be incorporated into the planning process to determine whether to continue maintaining the assets or upgrade them—or when to replace them with newer technologies.

Documenting assets and resources is a key activity to support managing TMS assets. Documentation can be considered the capture, management, and maintenance of more detailed information about TMS assets and resources. This information includes recording changes in the inventory as devices are upgraded, reconfigured, serviced, and removed from the inventory. The information also includes the management and configuration of resources that agencies use to manage, operate, maintain, monitor, evaluate, and report on the performance of TMSs. These resources may include policies, procedures, procurement documents, design documents, and product manuals.

CM is a series of processes and procedures for the purpose of establishing the consistency of a product's attributes for its entire lifecycle. CM verifies that changes have been carried out as prescribed and the documentation of assets reflects current configurations. CM of hardware,

software, documentation, and information are important activities to support the management and operation of a TMS and its assets. Smith's (2003) *Configuration Management for Transportation Management Systems* provides information about CM initiatives, processes, and practices for TMSs. TMSs continually evolve with the constant introduction of new technology, data sources, and device replacements. This evolution provides an opportunity for CM to help control system changes and modify documentation to reflect these changes.

This chapter provides an overview of how inventorying, documenting, and CM activities fit within overall TMS management. These activities help agencies assess their ability to monitor, manage, and control traffic and their ability to coordinate efforts and share information with other systems and stakeholders. This chapter also discusses how the practice of inventorying, documenting, and configuring TMSs can be leveraged for TSMO planning and TSMO project development. Figure 4 illustrates the relationships among inventorying, documenting, and configuring assets as part of managing TMS assets. This graphic introduces the topics contained in chapters 3–5. Chapters 6–8 explore current practices, challenges, opportunities, and trends as they relate to each aspect area.



Source: FHWA.
DMS = dynamic message sign; TAMS = Transportation Asset Management System.

Figure 4. Diagram. Relationships among inventorying, documenting, and configuring assets as part of managing TMS assets.

INVENTORYING TMS ASSETS AND RESOURCES

This section explores the importance of inventorying TMS assets and resources for agencies. It discusses the purpose and objectives of inventorying, and the various types of assets and resources that can be included in an inventory. Additionally, this section delves into the specific tasks involved in performing an inventory and examines the benefits of having an asset inventory. This section also discusses agency motivations for establishing an inventory, the tools that can be used to initiate or improve inventory efforts, and potential data entry issues that may arise during the inventory process.

Agencies establish inventories for various reasons. Some agencies want to know about the available asset information, resources being utilized, and conditions for better management.

Other agencies need an inventory as part of their policies and procedures due to insurance requirements. Access to a current inventory provides agencies several benefits, including awareness of the number and condition of their assets and which assets need maintenance or replacement and help with financial planning for routine maintenance, repair, and replacement costs.

When starting an initiative or effort to create an inventory, an agency may first consider checking what information on an inventory and records exist. These existing resources may be in different file formats or technologies and may need to be evaluated for their quality, including whether all desired TMS assets are included and if the information is up to date.

After an agency has assessed the status of any existing inventories, they may consider ways to increase awareness and garner support for updating or creating a new inventory. Providing a clear picture of the current inventory, records, and processes already in place can be helpful for increasing awareness and support. This process includes identifying any gaps in inventory information and existing processes that may be impacting the quality of the information contained in the current inventory. By understanding these issues, agency decisionmakers can determine the necessary steps to create or update an inventory of TMS assets and resources.

The process of establishing an inventory starts with recognizing that an inventory is an important part of better managing existing assets and resources. The tool(s) used to inventory or list assets and resources is another important consideration. Agencies use various tools for these purposes, including spreadsheets, specialized software, and online databases.

The process of creating an inventory involves carefully determining the assets and resources that are relevant and important to manage for the efficient operation of a TMS. When an agency selects assets and data that align with its goals and objectives, the inventory can effectively support the management of agency assets and the TMS's operation. When deciding what assets to include in a TMS inventory, agencies can review available information to identify gaps or additional data that may be needed to support improving how this information is used to manage these assets or their day-to-day operations. Additionally, considering the inclusion of resources, such as device manuals and standard operating procedures, can further enhance an inventory's usefulness.

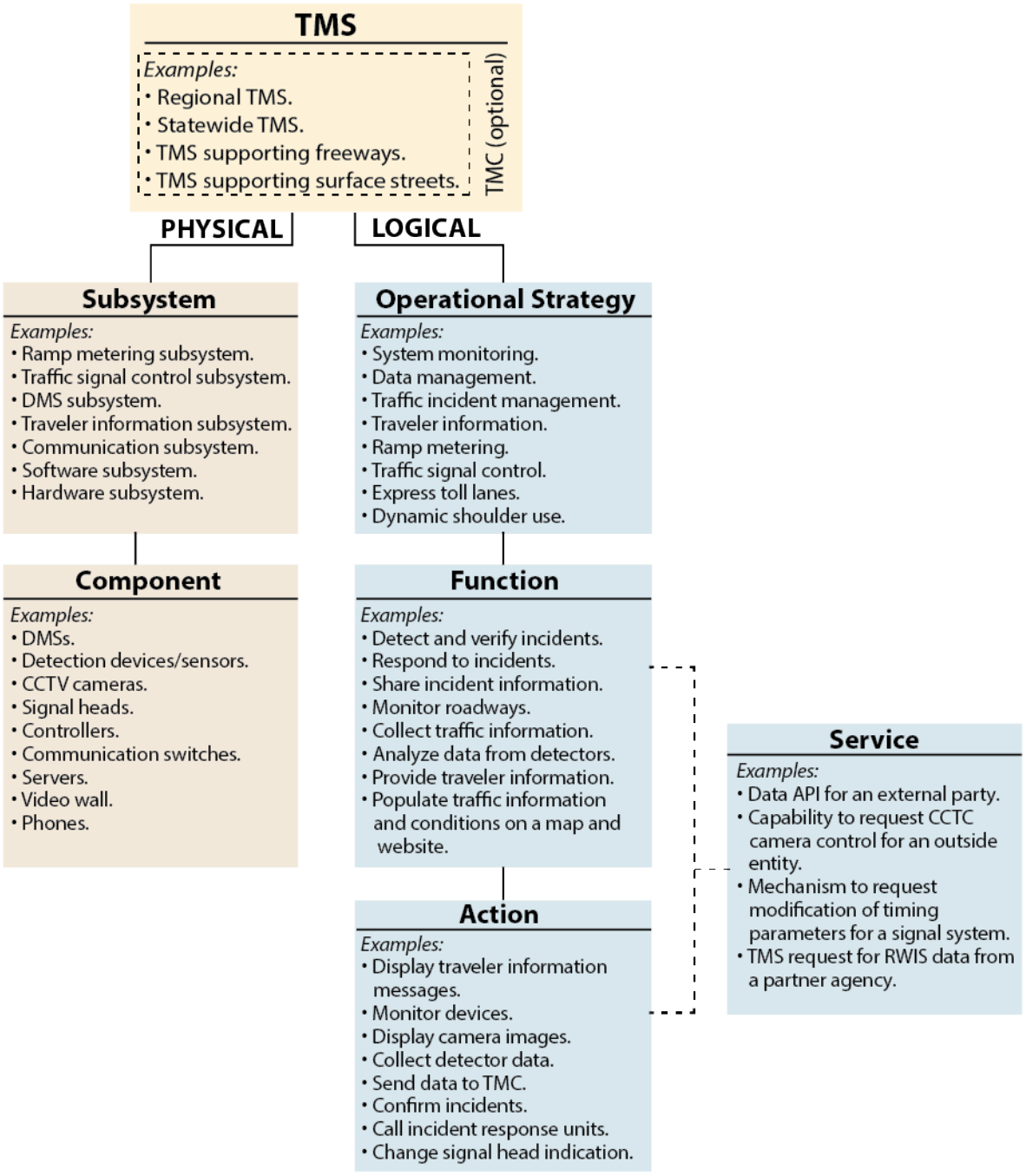
In addition, establishing a consistent and structured approach to categorizing and organizing the information in the inventory is a key consideration. This practice can help ensure that the inventory remains manageable and easily accessible for various stakeholders within the agency. By establishing clear protocols for data entry, updates, and retrieval, agencies can facilitate a more efficient and streamlined process for maintaining and using the inventory to support decisionmaking and operations.

Data collection can be initiated on receipt of new assets and resources or can be conducted after the assets have been deployed in the field. Ongoing data collection tasks can be incorporated into existing maintenance or operational processes. Identifying opportunities to maintain an inventory as part of ongoing agency activities ensures the inventory information stays current. Example activities that may impact an inventory and provide data updates include repair, maintenance, and device replacement. Integrating inventorying practices into existing agency processes may

require additional resources. Funding and staffing issues are factors to consider when considering efforts to initiate or update inventory efforts.

Figure 5 illustrates a TMS structure and provides examples of physical and logical elements. Within each element are example assets an agency can consider for incorporation into their TMS inventory. Following are examples of additional resources an agency can consider including in an inventory:

- Policies impacting TMS assets.
- Maintenance or operations contracts.
- Operations procedures.
- Maintenance processes.
- Device specifications.
- Device warranties.



Source: FHWA.
API = application programming interface.

Figure 5. Diagram. Detailed TMSs and processes (Miller et al. 2021).

DOCUMENTING TMS ASSETS AND RESOURCES

This section details the documentation process and discusses issues agencies may want to consider when incorporating documentation into TMS asset management activities. The section describes the specific tasks involved with documenting asset information, why the information is important, and their purposes and benefits.

Documenting TMS assets is the process of capturing and preserving information about the assets and resources that may be appropriate to include in an inventory. Documentation includes capturing additional information about an asset or actions taken on an asset. Examples of documentation include updating routine maintenance records for TMS devices or work order histories of devices that have had maintenance issues or failed.

Documenting TMS assets helps agencies understand the condition of their assets and may provide information to support future planning for maintenance and repairs. Documentation can also contain information that may help agencies make informed decisions when they explore replacing or improving specific assets. Monitoring and documenting the condition of assets is important to support the active management and operation of TMSs.

Agency personnel or contractors are typically responsible for keeping the inventory and supporting documentation updated. This process can be done through various activities, such as during ongoing system operations, device replacements, or dedicated data collection efforts. To ensure that the data remains current, agencies may consider establishing a regular update schedule or incorporate updates into existing processes.

Agencies with limited staff resources may choose to prioritize documenting the most important information, such as maintenance history. The documentation process can also serve as a verification mechanism to confirm details of the inventory data. By integrating the documentation updates into regular activities, agencies can maintain a reliable inventory that supports effective decisionmaking and system management.

Similar to inventory information, documentation on TMS assets and resources may be accessible to anyone in the agency who needs to use the information. In managing the access and use of these documents, some agency personnel may be assigned read access; meanwhile, others will be able to add additional documents. Access to documentation information will assist others within the agency as they prepare for future procurements, compare historical records of various assets, or incorporate information on these assets into other agency processes. Additionally, future planning efforts and future transportation improvement projects may benefit from access to historical TMS assets and resources.

One key aspect of documentation is capturing information related to monitoring, reporting, and maintenance of TMSs. This information, which includes the current performance and condition of TMSs, supports agencies in making informed decisions about whether to maintain, repair, or replace an asset. Documentation of preventive maintenance inspections and asset work order completions plays an important role in procurement processes when replacement assets must be purchased. By incorporating maintenance and performance data into documentation, agencies can also enhance the planning and programming of future projects impacting TMS operations.

Example resources for agencies to include in their TMS documentation include the following:

- Work orders.
- Maintenance records.
- Software changelogs.
- Product manuals.
- Manufacturer warranties.
- Standard operating procedures for managing and operating the TMS.
- Device performance history.

The process of inventorying TMS assets and resources also includes inputting the information collected into a database or resource selected to store and provide access to this information. To reduce data entry errors, agencies typically limit the number of individuals who can enter data into the inventory. Encouraging updates to the inventory as soon as possible after any device inspection, maintenance, repair, or replacement can improve data quality and completeness. Agencies may make accomplishing these updates possible by making the necessary tasks a part of an employee's or contractor's job duties and responsibilities.

During routine TMS operations, devices and components will eventually need to be removed for repair or replacement. Keeping data current as assets are moved or replaced is an important part of managing an inventory and TMS assets. Some agencies also periodically check their inventories throughout the year to ensure their inventories are current. Updated information on the asset's condition allows agencies to plan and program replacements for nonfunctional or obsolete devices and technologies.

CONFIGURING TMS ASSETS AND RESOURCES

A current understanding of all TMS assets, including their conditions, configurations, and any historical changes that may have been made, is important for managing and operating a TMS. This section discusses the process and benefits of managing inventories via CM. The discussion on CM includes all assets and resources of a TMS but also emphasizes the potential role of CM in managing and operating TMSs.

CM consists of processes, procedures, tasks, and actions to effectively control system changes. A benefit of CM for agencies includes the documentation of items reflecting the asset's physical design, procurement, construction, or installation. Another benefit of CM is the relative ease of finding information about what was installed, its location, and how it has been operating. Maintaining, repairing, changing, or replacing a subsystem, component, or device is more efficient if supporting documentation is available and reflects the up-to-date status of the system.

To begin a CM initiative or effort, a champion is usually needed to raise awareness of the importance of CM, to gain support, and to secure necessary resources. Developing a CM plan is a key step in initiating and sustaining a CM process and activities for a TMS. The plan will outline goals, responsibilities, and methods for implementing and sustaining a CM effort. The CM plan outlines key elements of the CM process, including the personnel who may be involved and their responsibilities, necessary resources, the tools to be used and their purposes, the baselining process, and configuration control. Raising awareness of the value and need for CM to

be an ongoing service that supports the ongoing management and operation of a TMS is important.

The CM process includes the following steps: (Smith 2003)

- Configuration identification.
- Change management.
- Configuration status accounting (CSA).
- Configuration audits.

Configuration identification refers to documenting items in the system, such as hardware or software components. Unique identifiers are assigned to each item to enable easy tracking of ongoing changes. This process improves the traceability of ongoing changes and the supporting information. Implementing configuration identification may include a centralized authority, or control board, to determine the configuration items and information collected about each item (Smith 2003).

Change management, or change control, involves assessing the impacts of change to a system, determining if the change goes forward, executing the change, and ensuring the changes are correctly and completely documented. The goal of change management is to determine the impact any proposed change may have on the entire system. Change management typically involves creating a change control board, which is an administrative group that approves change requests. Personnel typically involved in the process includes the manager; the facilitator assisting the manager; and the CM change control board members, who approve the changes requested to TMS assets (Smith 2003).

CSA is a process to guarantee that all documentation and change history about configuration items are up to date. The goal of CSA is to provide decisionmakers and stakeholders with the most current configuration information possible. CSA relates to managing TMS assets by identifying information to collect, data quality, and data governance processes. As TMS assets are replaced or repaired, CSA processes facilitate ensuring the ability to maintain the current configuration, condition, and status for each TMS asset (Smith 2003).

Configuration audits are used to ensure that changes to TMS assets have been implemented as approved, and the documentation reflects the current configuration. Additionally, configuration audits are used to verify that the changes were made according to the approval of the change control board and that documentation remains accurate and reliable. By applying CM to TMS asset inventories and documenting system changes, agencies can experience benefits, such as improved system maintainability, the ability to share information with other systems, and better integration with other systems (Smith 2003).

Managing TMS Inventory and Resources

Once an inventory has been initiated, additional tasks and activities are needed to keep the inventory accurate and up to date. Once an agency understands the assets currently available and their status, the agency can identify additional activities, practices, and resources that can be used to better manage the operation of its TMS and various assets. Communicating the value of an

inventory is important to ensure continued support and obtain the resources needed to keep the inventory current and facilitate the use of this information to help with operating a TMS and its assets.

TMS inventory management can benefit from existing agency activities and relationships. These relationships may exist to support other agency planning efforts. It may be possible to build on these relationships to develop a strategy for expanding current efforts to incorporate the management of TMS inventories and resources.

Some TMS assets are made of interchangeable components or subcomponents. Because of this interchangeability, agencies may keep an inventory of spare parts to provide quicker repair times. Agencies may consider including spare TMS parts in their TMS inventories, which can benefit agency efforts to forecast future needs for spare parts. Overall, these efforts support increased TMS performance (Weatherford et al. 2024).

Ideally, the TMS inventory is updated as new devices are added, old devices are removed, new software is installed, new resources are obtained, and new policies and procedures are adopted. The identification, incorporation, documentation, and availability of the information in the TMS inventory is all part of the process of initiating, managing, and maintaining the inventory. Chapter 6 provides more information on managing the TMS inventory.

Maintaining TMS Inventory and Resources

Regularly updating the information the TMS inventory contains, the tools that manage the TMS inventory, and the processes that support the TMS inventory is vital to creating a TMS inventory that is valuable over time. A CM program brings together all the necessary resources to keep the TMS inventory current and ensure the inventory is properly integrated into future activities and support contracts.

Having accurate and up-to-date information about the TMS inventory and the condition of assets is beneficial for the daily operations of an agency. This information helps agencies understand the overall condition, maintenance, and repair needs of a TMS.

Agency staff tasked with maintaining the TMS inventory effort need to first understand the value of their efforts. Additionally, staff needs access to and training on the processes, practices, activities, and tools that may be used to establish and then maintain a TMS inventory. Providing staff with clear procedures and resources for updating inventory information when conducting maintenance, repairs, replacements, or other activities that result in changes to the configuration of TMS assets is important.

Over time, the tools and resources used to manage the TMS inventory may need to evolve. TMS assets may grow in complexity, size, and functionality. The tools that support management of the inventory may need to be enhanced to continue providing holistic information. Chapter 7 provides more information on maintaining the TMS inventory.

Incorporating the TMS Inventory Into TMS Planning

A TMS inventory, which includes information about the subsystems and components that make up the TMS, provides a foundation for the effective management of assets and resources. Inventory information detailing the subsystems and components, such as age and condition, allows agencies to make important decisions about existing and future systems. This information may also be used to support the management and operation of the TMS, allocate resources, and perform various other activities.

Accurate and up-to-date TMS inventory information can also be used as input to inform TMS improvements as part of an agency or operations program's strategic plan. As an example, an agency's knowledge of the extent and condition of its ramp metering infrastructure allows the agency to designate the ramp metering infrastructure as a component or element of its TSMO program plan. Including the needs for ramp metering in the program plan serves as the impetus to proceed with planning and designing a project to improve or expand the service area of the ramp metering infrastructure (Weatherford et al. 2024).

Accurate inventory and information related to performance and condition of ramp metering assets helps agencies make informed decisions. This information may be used as inputs in an agency's selection and prioritization process for future improvement projects or the allocation of resources made available for the TSMO program or TMS. In this process, the needs of the ramp metering assets and to support the required operation may be considered along with other TSMO program resource needs and possible improvement projects (Weatherford et al. 2024).

The TMS inventory information can also be used to support planning for the next generation of an agency's TMS or specific improvements. Understanding the relationships among components and the typical error rates and historical conditions of assets can help agencies determine how the current condition or performance level may provide a basis to identify improvement opportunities. Additionally, this information can be used to develop or update requirements for designing and selecting technologies to support specific TMS functions, actions, and services.

CHAPTER 3. INVENTORYING TMS ASSETS AND RESOURCES

Inventorying assets and resources is the foundation of an agency's effort to manage its TMS assets. This process involves cataloging information, such as location, age, and condition. By having this information, agencies can better manage day-to-day tasks, such as monitoring the performance and condition of the assets and resources and conducting repairs or maintenance as needed.

To ensure efficient performance of a TMS, an agency must have a complete inventory of all TMS assets and resources. However, existing inventories may not have all the necessary information and data on TMS assets and resources. A complete TMS inventory will ideally include a thorough list of all TMS assets and resources, with accurate and up-to-date information on the status and condition of each device. The completeness of the inventory—in terms of both the number of assets included and the amount of information tracked—is important to the success of the TMS.

Agencies interested in creating or updating an inventory of TMS assets may begin by assessing their current inventory of TMS assets and resources. Initial questions for an agency to consider may include the following:

- Does the agency currently have an inventory, or inventories, of TMS assets?
- Is the information in the inventory of TMS assets current?
- Does the agency have a process for determining what classes of assets and information to consider including in an inventory of TMS assets?
- What specific processes within the agency can benefit from the information gathered in a TMS inventory? How does the agency plan to use this information to improve these processes?
- What tools does the agency use to track any existing TMS assets and resources?
- Which TMS assets or resources are not currently tracked in an agency inventory?
- How accessible is any current inventory information?

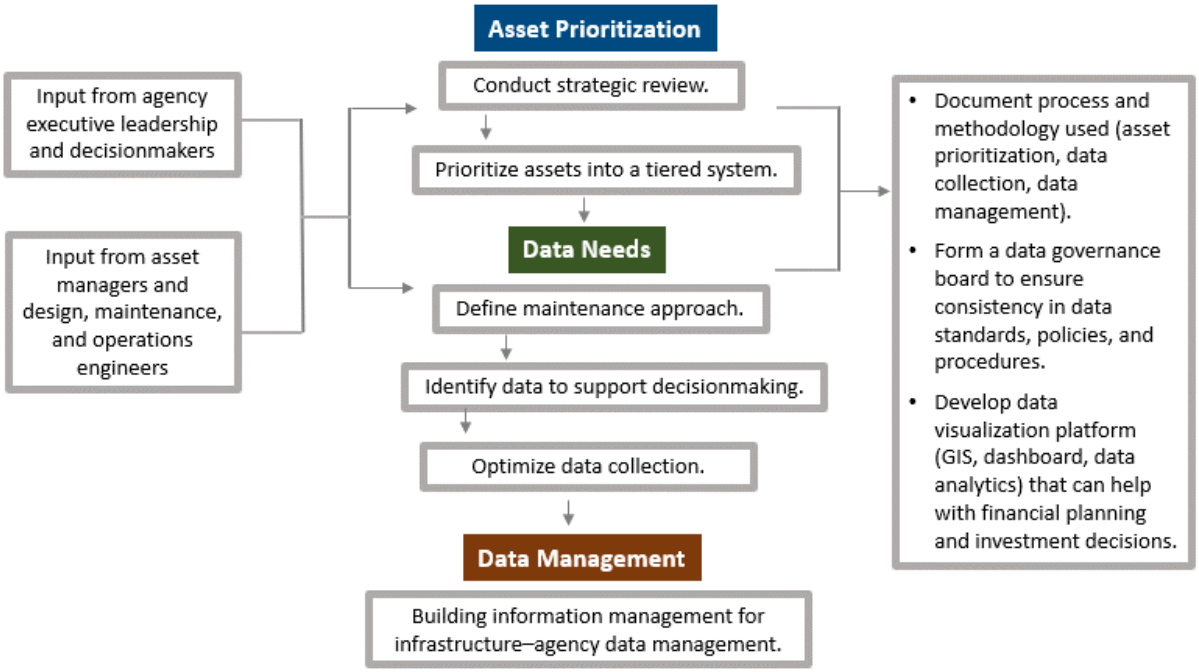
To ensure the effectiveness of a TMS, initiating and maintaining an inventory effort is crucial. This practice includes not only being familiar with the tools used to track the TMS asset inventory but also understanding the resources available and what additional resources may be needed to keep the inventory data up to date and complete. As TMS devices and resources change or maintenance is performed, updating the inventory to reflect this information and ensure the condition of assets is current is crucial. Additionally, understanding how the inventory information is used and how the information can be integrated with and used in other TMS or agency processes is vital.

Different levels of access may be needed to support managing the access and use of information in an inventory of TMS assets and resources. Some agency staff may be responsible for the inventory, updating it, and managing access for all users. Other agency staff may be responsible for maintaining data (e.g., quality, accuracy). Thus, both of these groups of staff may need read and write access to the inventory. However, some other agency staff may only need read access to the inventory information.

Maintaining a TMS assets and resources inventory enables agencies to make informed decisions about their day-to-day tasks. It also enables the use of this information to support decisions involving the allocation of resources (e.g., maintenance, repairs) or considering possible changes in how services are conducted (e.g., handle repairs and maintenance in-house or through outsourcing). Continuously monitoring the status of key devices is key to finding and detecting problems or failures. Information on asset conditions can be accessed through device status reports or a system performance dashboard. The information can also be used in the planning to upgrade, replace, or to make informed future decisions about the assets, supporting resources needed, and role for the TMS.

TMS ASSETS TO INCLUDE IN AN INVENTORY

Selecting the appropriate TMS assets to include in an agency inventory starts with identifying, prioritizing, and selecting the classes of assets to include. The TMS assets agencies can include in an inventory may involve CCTV cameras, changeable message signs, traffic detectors, ramp meters, cabinets, controllers, telecommunications subsystems, databases, software applications, and traffic signals. Agencies may begin by reviewing what inventory data are already available, what additional information is needed, what additional assets and resources can be added, what information may be needed to manage a classification of assets, the resources needed to collect and maintain this information, and the available resources to update or collect the needed data. Figure 6 presents a high-level framework for prioritizing what to include as part of an inventory of TMS assets and resources.



Source: FHWA.
GIS = geographic information system.

Figure 6. Diagram. High-level framework for prioritizing assets in an asset management program (Allen et al. 2019).

The information collected for TMS assets may vary among different subsystems and components. As shown in figure 6, agencies may consider prioritizing assets into different classifications or tiers of importance. Top tier—or tier 1—assets are most important to prioritize and include in an asset inventory. Information about tier 1 assets may be collected more frequently than information about lower-tier assets. Tier 1 assets may also be key to the management and operation of a TMS or specific subsystems or components.

Cost is another factor to consider when deciding which TMS assets to inventory. Developing, collecting, and maintaining an inventory can be a costly process. In light of this costliness, agencies may choose to collect and maintain data on only selected assets or attributes of a specific asset, based on what data the agency needs to manage and operate a TMS. Assessing whether the information collected will be useful in future decisionmaking regarding the management, operation, and maintenance of the asset, the TMS, or another agency process is important. Information may not be worth collecting at all if it is unlikely to support the necessary processes or decisions. By considering cost and the use of data in prioritizing what data to collect, agencies can ensure their asset inventory is developed and maintained to meet how they manage and operate their TMS—and that they have the staff and financial resources to support keeping the inventory current.

Once an agency has identified the key TMS assets to inventory, along with the data to collect and save, the agency can carefully consider how to effectively manage the inventory and information. This process involves determining how the information can be used and how to

maintain its accuracy, managing the use of this information, understanding how to support integration of this information into other key agency processes, and ensuring sufficient resources to meet these potentially evolving requests for services or information are available. This information on initiating, developing, managing the use of, and sustaining an inventory of a TMS inventory will be useful to understanding the information in chapter 4, where documentation on TMS assets and resources are discussed.

INITIATING THE EFFORT

When initiating the process of creating an inventory of TMS assets and resources, an agency may consider first assessing if any existing inventories or records are available. These resources may be in various formats, locations, or products. The agency may consider evaluating any existing source for the ability to access, feasibility to use, completeness, and accuracy of the information. Agencies can use the results of these evaluations to inform the process of initiating a new inventory or to determine the need or level of effort associated with updating an existing inventory.

Before an agency initiates any effort to create or update an inventory, communicating the value of having an inventory of TMS assets and resources to the agency is important. A clear understanding of the benefits of having an inventory may help garner support and facilitate obtaining the resources to initiate, complete, and sustain the effort. An inventory may provide insights into the current state of TMS assets, including their status and condition, which may inform decisionmaking regarding their management, operation, and maintenance.

An inventory of TMS assets and resources may also support agency planning, programming, and other processes. These processes may benefit from incorporating the consideration of the costs, condition, and resources that may be needed to manage, operate, and sustain an inventory of these TMS assets and resources. By highlighting the advantages of a TMS asset inventory, agencies can build a strong case for its creation, ensure its successful implementation, and maintain it effectively.

Agencies are likely, as part of their Transportation Asset Management program, to maintain an inventory of various infrastructure transportation assets. Some TMS assets may already be included in an enterprise asset management (EAM) inventory. Many States have recognized the importance of monitoring the health and condition of TMS and ITS assets as part of their agency infrastructure asset management inventories. However, only a limited number of the TMS assets may have been prioritized for inclusion in the EAM inventory.

Existing records may contain information about TMS assets. Any records approximating an inventory of different TMS assets may be appropriate to review and consider in tandem with any effort to initiate developing a TMS inventory. Multiple databases or records may possibly exist for individual TMS assets. For example, an agency may have a spreadsheet for its CCTV cameras and separate Web-based software for its traffic detector devices. These separate inventories may track different information and be maintained differently. Any existing records or information can serve as a starting point for identifying what information may be applicable to consider including in an inventory of TMS assets and resources. As an example, the California Department of Transportation (Caltrans) tracks common ITS field assets, such as CCTVs,

message signs, detectors, and ramp meters, but does not currently track communications equipment or hardware in its TMC.[1]

When considering and selecting which classifications or assets and what information to maintain and include as part of an inventory of TMS assets and resources, agencies may want to consider the following:

- What resources to include in the inventory.
- What classification of assets and information to include for specific assets in the inventory.
- The tool or tools used to collect, compile, and maintain TMS asset information.
- The resources (staff, contracts, or budget) needed to create a new inventory.
- The resources needed to update and maintain an existing inventory.

Common tools for saving data and information included in an inventory of TMS assets and resources may include spreadsheets, databases, and software. These tools often allow for clear definitions of data types, such as geocoordinates, dates, and serial numbers. The tools also enable the structured organization, collation, and cross-referencing of data. Additionally, if information is saved for many years, these tools may support using information from historical records for individual assets to generate reports summarizing TMS asset information.

When determining which assets and resources to include in an inventory, agencies can consider any assets or resources tied to the efforts to manage its TMS assets. Resources, such as the Capability Maturity Model approach and the TAM Gap Analysis Tool, allow agencies to determine gaps and next steps toward improvements (American Association of State Highway and Transportation Officials (AASHTO) n.d., 2014). Examples of resources that can be added as part of the inventory include agency policies, procedures, standard operating procedures, device warranty information, and manuals. Since agencies may face financial constraints that prevent them from collecting inventory data on all desired TMS assets at once, a prioritization process may help agencies determine which data are initially collected and incorporated. For example, the Mid-America Regional Council's (MARC) Operation Green Light tracks its asset inventory information in a single database (MARC 2022). MARC's accounting department documents any asset worth at least $1,000 for insurance purposes.[2]

After determining what assets to include in the inventory, agencies may consider identifying the necessary information to collect. The agency can then determine what existing information can be incorporated and integrated into the database or what software can be used to manage the inventory. Any missing information can be identified, and a plan can be prepared to collect, compile, and include it in the inventory. This process may involve establishing new data collection procedures. Table 1 lists the assets an agency can consider including in the TMS asset inventory.

[1]Interview with Caltrans staff member, 2021.
[2]Interview with MARC staff member, 2021.

Table 1. Examples of TMS inventory assets.

Asset Class	Asset Type	Asset Examples
Field devices	Cameras	• CCTV traffic cameras. • Video detection. • Camera—RWISs.
Field devices	Connected and automated vehicles	• Roadside units. • Antennas.
Field devices	Emergency call boxes	Call boxes.
Field devices	Highway advisory radios	Broadcast units.
Field devices	Message signs	• DMSs. • Blank outs. • Queue warning signs. • Sign controllers. • Portable changeable message signs.
Field devices	Sensors	• Traffic detectors. • Commercial vehicle dimension wireless data collectors. • WIM stations. • Roadway intersection conflict warning systems.
Field devices	RWISs	• Environmental sensing stations. • Noninvasive pavement sensors. • Road sensors.
Field devices	Traffic control	• Controllers. • Gates. • Lane control. • Preemption signals. • Ramp meters. • Reversible lane signs. • Signals. • Variable speed limit signs. • Warning flashers.
Field devices	Traffic detection	Detectors.
Field devices	WIM	• Fixed. • Portable.
Field devices	Communications	• Fiber. • Modem. • Switches. • Copper. • Wireless.
Communications	Networking	• Networking hardware. • Video equipment.
Communications	Servers	• Onsite server facilities.

Asset Class	Asset Type	Asset Examples
		• Onsite servers. • Workstations.
Hardware/software	State-owned, licensed, cloud-based software	• Asset management. • Connected vehicle. • GISs/linear referencing systems. • Maintenance decision support systems. • Traffic management. • Traveler information systems. • Video management systems.
Hardware/software	Mobile	• Probes (e.g., snowplows). • Safety service patrol courtesy vehicles. • Incident response vehicles.
Portable	Portable	• Smart work zone. • Arrow boards. • Portable DMSs, cameras, etc.
Field devices	WIM	• Fixed. • Portable.

RWIS = road weather information systems; WIM = weigh-in-motion.

Once the agency has selected a list of TMS assets and resources to include in an inventory, the agency may want to consider attributes or information to collect, save, and manage. The attributes selected for an agency's TMS asset inventory provide the basis for identifying what data may need to be collected. Choosing attributes that are key to effectively managing TMS assets, supporting the management and operation of the TMS, and meeting the needs of other agency processes is important. Asset attributes that can be used as part of a TMS asset inventory include the following:

- Location.
- Original installation date.
- Last date serviced.
- Asset condition.
- Functional description.
- Make, model, and serial number.
- Original purchase cost.
- Maintenance costs.
- Firmware version.
- System environment—Electronic platform on which the asset operates.
- Infrastructure—Elements required for asset functionality.

SUSTAINING THE EFFORT

Sustaining a TMS asset and resource inventory effort involves ensuring that the inventory accurately reflects the following:

- All TMS assets and resources.
- The current status or condition of each asset.
- Relevant details and information about each asset and resource.

TMSs are complex and integrated systems that are constantly undergoing changes and upgrades. Individual TMS assets and resources are frequently updated, modified, repaired, and replaced, which increases the complexity of the TMS. Having an up-to-date inventory of TMS assets and resources supports the agency with maintaining, repairing, assessing, managing, and reporting on the performance of TMSs.

To sustain a TMS asset inventory, staff time and resources are needed to integrate inventory maintenance steps into existing agency processes. Agencies may need to review the budget, staff resources, tools, and services (e.g., support contracts) that are available to support maintaining and managing their asset and resource inventories. In some cases, agencies can revise existing agency processes (e.g., ITS maintenance practices, operating procedures) to include new steps to ensure regular maintenance work is reflected in the TMS asset inventory. In other cases, agencies may need to integrate information on actions and services performed (e.g., maintenance or repair tickets) to support the management and operations of a TMS into the inventory of TMS assets and resources.

An agency's ability to maintain a TMS asset inventory may be hindered by limited resources or constrained budgets. Although it is ideal for agencies to have complete inventories of all assets and an assessment of asset conditions, existing constraints may affect the quantity and quality of what information is actually included in a TMS asset and resource inventory. In such cases, agencies may prioritize asset classifications and specific data points for each type of asset based on the available resources. This approach enables agencies to focus on the most important assets and data while gradually expanding the inventory as resources become available. Effective prioritization and resource allocation can help agencies make the most of their existing resources.

Agencies may want to consider the following questions when encountering resource constraints that impact the ability to maintain a complete inventory:

- Can the classification of assets to be included in the inventory change?
- Can the information identified to be collect and maintain be changed for different classification or types of asset be reduced to only the highest priority items?
- Which processes associated with collecting, compiling, and saving information for each type of asset are adding the most demands to the agency's limited resources?
- Can any of the existing processes be automated or modified to improve efficiency?

Sustaining the effort may also involve a quality assurance (QA) process to verify the quality of the data being saved and verify the asset inventory is current. Some agencies may enact an inventory scheduled to review asset inventory information on a regular schedule (e.g., quarterly). Inventory QA policies, procedures, and scheduled oversight reviews may also be used to check the status of inventory updates and verify inventory accuracy.

As an example, Virginia DOT (VDOT) uses randomly generated inventory reports to check and verify asset inventories are current.[3] The reports randomly select 5 or 10 percent of the assets in its inventory for verification. Verification is done by VDOT staff, who manually review asset information, such as location and status, and compare the information to the device information contained in the asset inventory. Updated information is important, as agencies may also track asset lifecycle information for several years to create historical data that assist with maintenance and replacement efforts.

Throughout the study, researchers observed some common themes and lessons learned from agency's day-to-day actions and tasks, as follows:

- Simplify the inventorying effort as much as possible (e.g., identify a limited amount of data to collect, especially if not all the asset information is used in various TMS or agency processes or decisionmaking). Support resources are limited. If asset inventory maintenance processes are too cumbersome, some staff may abandon the task.

- Reduce disparate tools and sources of information for tracking and inventorying TMS assets. Agencies managing multiple data bases or sources of records containing inventory information may find it more challenging to integrate these records in the future. One database or location where all information contained in an inventory of TMS assets is easier for an agency to manage, maintain, and sustain.

- Consider the time and effort needed to explain to staff the importance of updating and maintaining an inventory of TMS assets. When the importance of the effort and their roles are identified, staff is often more inclined to support the effort.

- Consider the use of open-source tools, which are flexible to use, to support collecting, processing, and saving information from multiple sources. For example, some staff may be updating the inventory from the field using mobile devices, and other staff may be updating the system from a desktop computer.

- Provide an application programming interface to encourage integration into other technologies and systems to compile, store, and manage the inventory information.

[3]Interview with VDOT staff member, 2021.

USING THE INFORMATION

An inventory of TMS assets and resources contains valuable information. Capital costs and warranty information give a picture of the agency's investment in its assets and the level of protection against device failures. Asset histories may contain details, such as procurement date, deployment date, maintenance history, and operational costs. This information may help the agency evaluate the asset's performance throughout its lifecycle. This information may allow agencies to make informed decisions as they manage and operate their systems and plan for future improvements.

For example, agencies can monitor the operating statuses and conditions of vehicle detectors to gather information on detectors that may require maintenance or repair. This monitoring can be important, because vehicle detectors may assist with managing how travel times are generated. Thus, if a significant number of detectors are not functioning properly, the generated travel time information may be unreliable and inaccurate.

Several challenges exist with using asset inventory information, including the following:

- Use of outdated database and tools.
- Data quality, missing information, and need for quality control (QC).
- Inconsistent identification and definition of data to collect and save for different types of assets.

Many of the existing tools that agencies may be using to manage TMS asset inventories may be outdated. Some agencies still use databases and tools with limited capabilities. Upgrading to a tool that integrates analytics is an example of an enhancement to tools being used. Another issue limiting agencies' abilities to use inventory information is the completeness and accuracy of the data collected for TMS assets and documentation. When information is missing, not accurate, or not easy to use, the inventory is more likely to become outdated. Lack of asset inventory accuracy can also be caused by lacking QA and QC processes associated with the data entry process or data update processes. Table 2 details these challenges and several others and suggests strategies to address the challenges.

Table 2. Inventory challenges and issues.

Challenge/Issue	Likelihood	Severity	Opportunity/Mitigation
Traditional relational databases difficult to maintain, especially older versions	High	Medium	Consider using a multiuser asset management tool that leverages a modern backend database.
Process for multiple jurisdictions to perform data entry into a common tool	Low	Low	Research potential tools that meet multiuser requirements to encourage tool sharing.
Setting update schedule and following through/enforcement	Medium	Medium	Ensure data are kept accurate and updated in a timely fashion.
Data integrity, QA and QC	Low	High	Establish QA and QC processes to verify data accuracy and use drop-down menus for data entry where possible to standardize data entry.
Incentivizing and prioritizing.	Medium	Medium	Emphasize the importance of data completeness and accuracy
Assigning responsibilities	Medium	Medium	Create ownership of each step of the process.
Inconsistent definition of assets	High	Medium	Develop consistent and accepted definitions.

INCORPORATING INVENTORY INFORMATION INTO AGENCY PROCESSES

Having up-to-date data in an inventory can benefit other decisionmaking processes, such as planning, project development, prioritization, and programming. For example, an agency may have a number of CCTV devices that are several years old and becoming outdated. At the same time, new technological advancements may become available, providing opportunities to replace the older cameras. If an asset inventory has been maintained, it will contain the information necessary for the agency to plan and develop a project to replace the CCTV assets. The agency's confidence in the inventory enables project prioritization, project programming, and ultimately, project delivery.

The following trends may impact TMS asset inventorying:

- Tracking the condition of a TMS asset as a part of the information included with different devices across the agency. Agencies may see the base inventory as the first step toward tracking asset health and then learn why the asset may be failing. Several agencies noted that future investments in TMS assets cannot or will not be done without the agency first understanding the current performance—and creating the inventory is a first fundamental step (Weatherford et al. 2024).

- Establishing a recurring replacement or upgrade plan. For example, States may continuously upgrade specific TMS assets on a routine basis (e.g., 20 of the oldest devices every 2 yr). The asset condition, age, and history are used to create this replacement plan (Weatherford et al. 2024).

- Incorporating inventory information into maintenance contract performance requirements. Agencies may incorporate the asset status and condition into the contractual agreement between the agency and certain device maintenance vendors (Weatherford et al. 2024).

CHAPTER 4. DOCUMENTING TMS ASSETS AND RESOURCES

Documenting is a key component of how a transportation agency manages its TMS assets and supporting resources. Documentation is the capture and compilation of information for TMS assets and resources. Documentation involves recording changes in the inventory as devices are maintained, serviced, upgraded, reconfigured, and removed. Documentation also includes the management and configuration of resources agencies use to manage, operate, maintain, monitor, evaluate, and report on the performance of TMSs. Additionally, it includes recording asset performance history to support lifecycle cost assessment and planning for future investment. Resources may include policies, procedures, agreements, procurement documents, design documents, and product manuals.

The objective of this chapter is to provide insights on the issues agencies may want to consider in support of documenting TMS assets and resources. The chapter discusses the definition, importance, and benefits of documenting. Documentation must be a continuous and recurring activity to yield effective results. The act of documentation is the initial capture and compilation of information, which is similar to, but different from, the CM of this information. Figure 7 depicts a TMS asset report and displays asset condition on a dashboard. The information shown in figure 7, such as asset name, asset type, and asset status, is maintained by agency documentation processes.

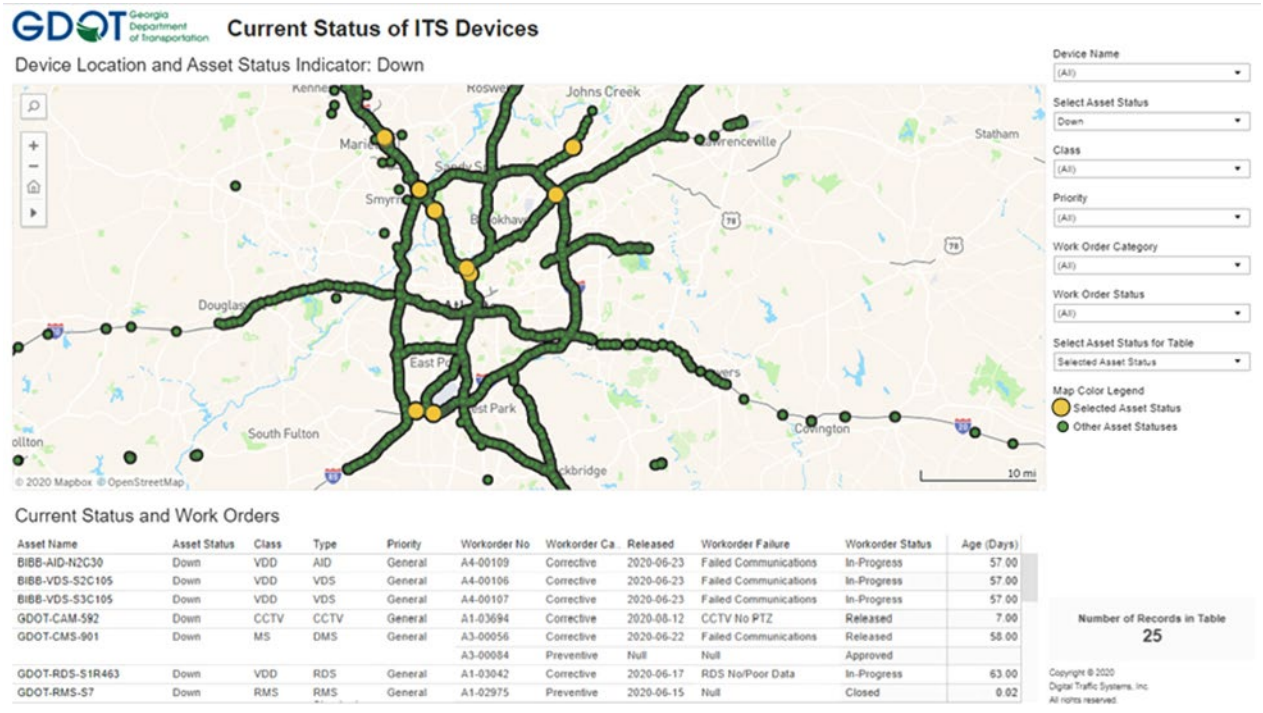


Figure 7. Screenshot. Asset information benefiting from documentation (Hibbard n.d.).

This chapter addresses the motivation behind documenting and the benefits to agencies. The chapter discusses the process, specific tasks, documentation maintenance, documentation

management, and the establishment of device baselines and performance levels. This chapter also addresses how the documentation is integrated with other processes or activities associated with managing the TMS, such as maintenance, repairs, purchasing new devices or equipment, and developing new projects. Information will be presented on current practices and gaps, challenges, opportunities, and trends related to documenting TMS assets.

INITIATING THE EFFORT

Documentation involves recording changes in the inventory as devices are upgraded, reconfigured, serviced, and removed. Documentation also includes records of performance history to support lifecycle cost assessment and future investment planning. This information is key for managing the resources used to influence TMS operations.

The process of documenting assets and resources is important because it provides information about the current and past status of the assets. QA and scheduled oversight reviews can be used to verify the information has been captured, and the documentation is accurate. Agencies may keep track of lifecycle information for several years to build historical data that can inform future device maintenance and replacement decisions.

An agency's motivation to document assets is to gain a comprehensive understanding of the asset's condition and performance. Tracking the device's preventive maintenance schedule and any work orders issued and completed provides a better understanding of the asset's condition. Documentation also provides a proper historical understanding of the asset's lifecycle.

The key steps in the documentation process include starting from scratch, assessing existing documentation for gaps, and determining if documentation enhancements or updates are needed. To start from scratch, the agency must first determine what information has been captured, assess its accuracy, and correct any inaccuracies. The agency can also review existing documentation for gaps, such as missing policies, procedures, manuals, or device warranty information. Documentation enhancements and updates are important to keep information accurate. For example, updating documentation to reflect the status change of a device, from down to operational after a work order has been completed, provides a more accurate system status.

When interviewed, agencies provided the following information about their documentation practices and lessons learned:

- Oregon DOT (ODOT) leadership believes documenting only the truly necessary information is important to ensuring the process does not become too complicated and cumbersome.[4]

- Tennessee DOT (TDOT) adopts a similar approach and only collects necessary data as part of its EAM efforts. TDOT also uses existing tools that are familiar to staff to protect against unnecessary user errors.[5]

[4]Interview with ODOT staff member, 2021.
[5]Interview with TDOT staff members, 2021.

SUSTAINING THE EFFORT

Considering the level of effort and cost involved in documenting assets, maintaining inventories and sustaining these efforts is important. These factors may drive decisions regarding what assets are inventoried and what documentation is maintained or not maintained. For example, in the case of documentation maintenance, when routine asset maintenance has been completed, the data and results from the maintenance activity are logged into the inventory tool to document the activity. The documentation is included as one of the final steps of the routine maintenance process. Another example of updating documentation is when a failure causes a system component to be removed for repairs and another component is substituted in its place. Documenting this change, even though the repair is not part of a routine asset maintenance effort, is beneficial.

To emphasize the importance of documenting assets and resources, communicating the benefits of maintaining the records, especially when updates are being made following routine or emergency repairs, is advantageous. Key stakeholders involved in various aspects of managing the documentation may include the following:

- Operations staff, who may be receiving the initial alert of an asset failure.
- Maintenance staff, who are responsible for replacing devices.
- Procurement staff, who are responsible for ordering new devices.
- Contracted support staff, who are responsible for maintaining asset devices.
- Administrative staff, who are responsible for supporting documentation procedures.

The objective of sustaining documentation management and control is to reduce the amount of time from when asset information changes (e.g., condition, status, location) to when the documentation is updated. Information updates processed as soon as possible after changes are made reduce the likelihood of a gap between the actual asset condition and the documented asset condition. The processes established to manage documents of TMS assets and resources ideally clarify exactly which staff or group is responsible for updating the documentation in the following instances:

- Routine maintenance.
- Emergency repairs.
- Systemwide or areawide upgrades.
- New technology installations.

Agencies provided information during interviews about their documentation practices, day-to-day actions, tasks, and lessons learned. Staff from the Lake County, IL Division of Transportation mentioned that keeping information up to date is complicated due to multiple systems, lack of access to some systems in the field, and varying levels of experience and understanding of system input needs.[6] DOT believes data accuracy is important and recommends involving QA and QC staff and procedures.

[6]Interview with Lake County, IL, Division of Transportation staff member, 2021.

VDOT uses EAM software for its asset inventory. VDOT has asset management standard operating procedures for all ITS devices. VDOT's maintenance contractor is required to maintain VDOT's assets, so VDOT has a well-documented procedure from the birth of an asset through its end of life, decommissioning, and disposal. VDOT runs reports through its EAM software to identify and verify the desired level of performance associated with the asset's condition. At the end of each quarter, a custom report shows when work orders were opened and closed and if any asset repairs were made within the 4-hr window specified by a service-level agreement (SLA). VDOT's EAM software is used to manage the operational uptime of the system, the operational availability, and the work orders associated with failed units.[7]

Regarding the amount of data collected and maintained and the level of effort required to do so, VDOT indicated it is collecting only what is really needed. Once the initial inventory is done, VDOT still needs to track these devices and keep the data accurate. To ensure the documentation of TMS assets and resources remains accurate and reliable, VDOT runs a fiscal cost report at the end of every month. This fiscal report highlights which assets were relocated, and this information must align with what is indicated in its software. The report is called a cost report, because as pieces of equipment on the shelf are deployed in the field, a financial transaction must occur internally. VDOT must make sure it knows where every single piece has been placed. This report helps VDOT track assets and flag inconsistencies.[8]

Other practices, tasks, and lessons learned from agency interviews and document reviews include the following:

- Document only the truly necessary information to ensure the process does not become too complicated and cumbersome.
- Document and store TMS asset information into one centralized repository for easier data analysis.
- Involve QA and QC staff in as many procedures as is reasonable to ensure data accuracy.

USING THE INFORMATION

The information that documents the assets and their current conditions helps agencies operate their systems' day-to-day tasks. Agencies use several different methods to establish asset baselines and desired performance levels, which include the following:

- Basing the condition of assets relative to manufacturer's recommended service life.
- Updating the percentage of the device's expected useful life based on the most recent inspection or testing; in this case, the expected useful life is updated after each inspection.

[7]Interview with VDOT staff member, 2021.
[8]Ibid.

Among common agency trends for labeling TMS asset performance levels, one common method is to group condition into one of four categories: good, low risk, medium risk, and high risk. Other agencies use identifiers such as good, fair, and poor to identify asset performance levels. Asset documentation allows agencies to make informed decisions about the assets.

Regardless of the method used to establish asset baselines, agencies can use the information to decide whether to repair devices or replace them with newer technology. Asset performance information, such as good, fair, and poor, also allows agencies to make informed decisions about continuing to repair assets or completely replacing assets. Access to the documented asset information is important for decisionmakers and all involved parties within the agency.

As part of the agency interviews, TDOT discussed its twofold approach to managing access to the asset information captured as follows: [9]

- Only a limited number of people are given write access to enter information into the spreadsheets or databases.

- All decisionmakers and managers are given read access to the information and reports generated from the documents.

Michigan DOT creates monthly updates of its prioritized TMS assets. These updates enable continuous at-a-glance reviews of the health of various TMS assets. Table 3 is a checklist Michigan DOT uses for monthly status checks of its DMSs. Table 4 is a monthly checklist Michigan DOT uses to document CCTV camera conditions.[10]

[9]Interview with TDOT staff, 2021 .
[10]Interview with Michigan DOT staff, 2021.

Table 3. Michigan DOT's monthly ITS checklist for DMSs.[11]

Device Name	Check 1: July 1, 2021	Work Order: July 1, 2021	Check 1: July 2, 2021	Work Order: July 2, 2021
A-Dequindre-LA33000S-14 Mile	COMMS	15779	COMMS	15779
A-Dequindre-LA33000S-14 Mile-2	COMMS	15594	COMMS	15594
A-Dequindre-LA37000N-Big Beaver	Good	—	Good	—
A-Dequindre-LA37000N-Big Beaver2	Good	—	Good	—
A—I75N-MM0570-N of McNichols	Good	—	Good	—
~~A-I75N-MM0580-N of 7 Mile~~*	—	—	—	—
~~A-I75N-MM0580-N of 7 Mile1~~*	—	—	—	—
A-I75N-MM0592-N of 8 Mile	COMMS	16691	COMMS	16691
A-I75S-MM0578-7 Mile	Good	—	Good	—
A-I75S-MM0585-N of State Fair	—	—	—	—
A-I75S-MM0588-S of 8 Mile	COMMS	17821	COMMS	17821
A-I696E-MM00265-Hayes	Good	—	Good	—
A-I696E-MM00265-Hayes 2	Good	—	Good	—
A-I696E-MM0197-Dequindre	Good	—	Good	—
A-I696E-MM0197-Dequindre 2	Good	25500	Good	25500
A-I696E-MM0230-VanDyke	Good	—	Good	—
A-I696E-MM0230-VanDyke 2	Good	—	Good	—
A-I696E-MM0240-Hoover	Good	—	Good	—
A-I696E-MM0240-Hoover 2	Good	—	Good	—
A-I696W-MM0198-Dequindre	Good	—	Good	—
A-I696W-MM0198-Dequindre 2	Good	—	Good	—
A-I696W-MM0229-VanDyke	Good	—	Good	—
A-I696W-MM0229-VanDyke 2	Good	—	Good	—
A-I696W-MM0240-Hoover	Good	—	Good	—
A-I696W-MM0240-Hoover 2	Other	23182	Other	23182
~~A-I696W-MM00284-Gratiot~~*	—	—	—	—
A-I696W-MM0284-Gratiot 2	Good	—	Good	—
A-Rochester-LA2808N-I75 Ramp	Good	—	Good	—
A-Rochester-LA2808N-I75 Ramp-2	Good	—	Good	—
A-Rochester-LA2808N-I75 Ramp-3	Other	22130	Other	22130
A-Rochester-LA3000N-Big Beaver	Good	—	Good	—
A-Rochester-LA3000N-Big Beaver-2	Good	—	Good	—

—Not applicable.
*As received.
COMMS = communication system.

[11]Interview with Michigan DOT staff, 2021.

Table 4. Michigan DOT's monthly ITS checklist for CCTV cameras.[12]

Device Name	Status Name	System	Check 1: July 1, 2021	Work Order: July 1, 2021	Check 1: July 2, 2021	Work Order: July 2, 2021	Check 1: July 3, 2021	Work Order: July 3, 2021
C-I275N-MM0092-Willow	Maintenance	ATMS	Good	—	Good	—	Other	25711
C-I275S-MM0106-S Huron	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275S-MM0127-Sibley	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275S-MM0127-Sibley 2	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275N-MM0137-Pennsylvania	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275N-MM0147-Eureka	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275S-MM0164-S Huron River	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275S-MM0181-Hannan	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275S-MM0190-Tyler	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275S-MM0200-Ecorse	Maintenance	ATMS	Pan/tilt	23574	Pan/tilt	23574	Pan/tilt	23574
C-I275N-MM0221-Michigan	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275N-MM0230-N of Michigan	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275N-MM0240-Cherry Hill	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275S-MM0250-Ford	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275S-MM0257-Warren	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275N-MM0263-Koppernick	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275N-MM0276-Ann Arbor Rd	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275S-MM0276-Ann Arbor Rd 2	Maintenance	ATMS	Spinning	25697	Spinning	Serviced	Good	—
C-I275N-MM0285-Plymouth	Maintenance	ATMS	Good	—	Good	—	Good	—
C-I275S-MM0294-M14	Maintenance	ATMS	COMMS	25646	No vid.	Serviced	Good	—
C-I275S-MM0250-Ford	Maintenance	ATMS	Good	—	Good	—	Good	—

—Not applicable

ATMS = advanced transportation management system. No vid. = no video

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[12]Interview with Michigan DOT staff, 2021.

Maryland DOT State Highway Administration (MDOT SHA) indicated its asset documentation procedures are focused on monitoring operational status to identify failures early. This process facilitates a proactive maintenance response and informs the agency's priorities for repairs. MDOT SHA's current tools contain only a limited amount of information about individual assets and are configured to primarily allow for basic monitoring and periodic reporting of the necessary operational conditions. The lack of a single comprehensive system makes obtaining a big-picture view of assets challenging.[13]

Several issues or challenges related to using asset documentation information that MDOT SHA faced include the following: [14]

- Improving documentation standards.
- Creating a list of commonly needed documents.
- Maintaining documentation control.
- Identifying the staff involved in the documentation process and being clear on staff responsibilities.

Table 5 lists these challenges, along with a few others. Along with each challenge is the opportunity or mitigation strategy to address the challenge.

Table 5. MDOT SHA documentation challenges and issues[15]

Challenge/Issue	Likelihood	Severity	Opportunity/Mitigation
Documentation standards as relating to TMS assets; no complete de facto standard to follow.	High	Medium	Investigate and adopt applicable IEEE standards.
Creation of list of commonly needed documents.	High	Medium	Work backward from intended use of the documents; agree on the minimum desirable documentation needed to achieve this result.
Documentation control.	Medium	Medium	Investigate ISO® standards, such as ISO 9001:2015, and adopt applicable recommendations (ISO 2015).
Creation of process documentation.	Medium	Low	Create a list of all steps required to maintain important documents.
Staff.	High	High	Simplify responsibilities, identify clear owners, and explain the importance of each task.
Inventory integration across various subsystems and platforms.	Medium	Low	Integrate systems to encourage automation of updates or QA verification, where possible.

ISO = International Organization for Standardization.

[13]Interview with MDOT SHA staff members, 2021.
[14]Ibid.
[15]Ibid.

INCORPORATING DOCUMENTATION INFORMATION INTO AGENCY PROCESSES

Inventorying data and maintaining documentation well provides information that may be used to inform planning, project prioritization, and project programming processes. When work orders, maintenance repairs, and maintenance histories easily identify assets ready for replacement, agencies can use this information to plan and develop future projects, prioritize future projects, program future projects, prepare procurement documents to purchase new assets or devices, and integrate the information as part of the documentation process.

One trend is for agencies to use the documentation of TMS assets and resources to create a routine preventive maintenance program. For example, many agencies have established a semiannual preventive maintenance replacement program for specific TMS assets (e.g., CCTV cameras). The historical depiction of asset condition and performance, if properly documented, allows the agency to more efficiently create a plan to replace aging or failing devices as part of a project. Other agencies have introduced lifecycle planning (LCP) as part of their efforts to manage TMS assets.

A comprehensive LCP process generally includes any of the following components:

- Setting objectives and performance measures—Including asset condition and minimum acceptable performance to align with agency strategic priorities.

- Implementing preventive treatments—Maintenance activities performed over the life of an asset following a comprehensive LCP analysis process to determine the most cost-effective approach, based on asset performance.

- Using deterioration models—Applying analysis or performance models reflecting changes in asset conditions with and without preventive maintenance.

- Establishing targeted conditions—Setting interim targets reflecting time-constrained thresholds.

The authors discovered the following gaps related to the documentation practice during the literature review and interviews:

- Types and levels of sophistication in documenting TMS assets vary widely across agencies. These variations are reflective of several factors, including the relative maturity of an agency's TSMO or ITS programs, the scale of previous TMS asset investments, and the organizational constitution's approach to transportation asset management (FHWA 2022).

- Agencies use many different tools to track transportation asset performance. These variations partially result from agencies adapting existing tools that were previously used to document traditional infrastructure assets (i.e., bridge assets, highway assets, facilities, communications) rather than developing and implementing dedicated tools for TMS asset documentation ((FHWA 2022).

- The importance of accuracy and balancing the completeness and simplicity of TMS asset documentation (FHWA 2022).

- In general, it is important to select the right information for the purposes of monitoring TMS asset location, condition, configuration, and performance. The research team identified some common data elements (e.g., location and condition), but a single set of data elements was not immediately identifiable from the literature review or interviews.

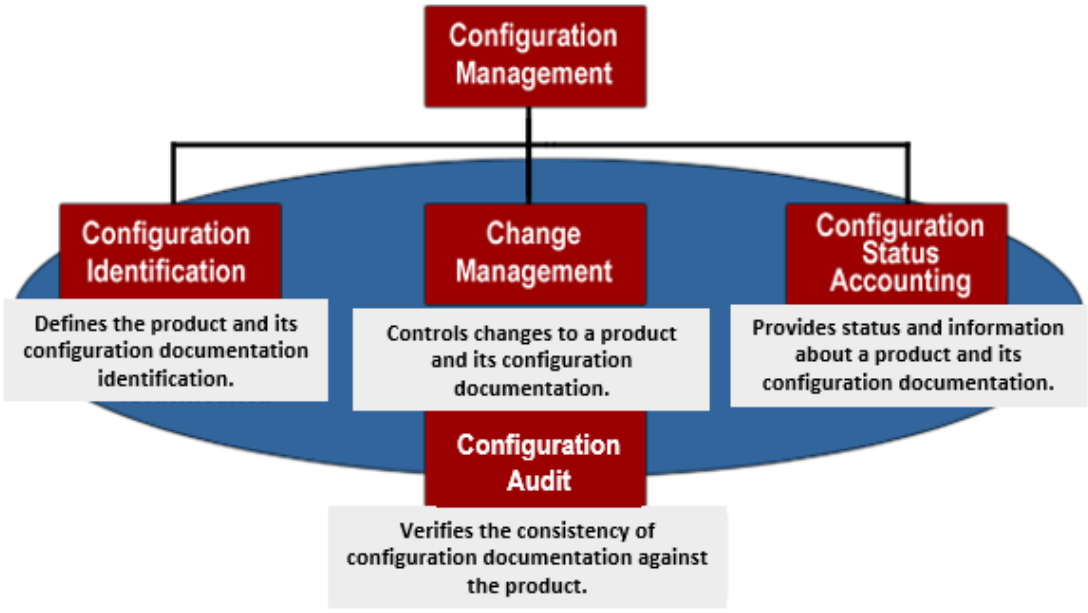
CHAPTER 5. CONFIGURING TMS INVENTORY AND RESOURCES

The purpose of this chapter is to provide insights on configuring TMS assets and resources. This chapter defines and discusses the importance and benefits of configuring assets and resources. The chapter also discusses initiating and sustaining the process, assigning resources, and involving stakeholders, who participate in or lead efforts to manage the configuration of TMS assets. Additionally, information is presented on current practices, challenges, trends, and issues with configuring TMS assets. This chapter also describes how configuring these assets builds on the practices of inventorying and documenting TMS assets highlighted in the previous chapters.

CM consists of processes and procedures for effectively controlling system changes. CM of computer hardware and software is a valuable aspect of an agency's ability to manage its TMS. Including all assets and resources of a TMS in CM, which can include field devices, communication systems, and documentation such as policies, procedures, and manuals, can be beneficial.

Many existing agency processes are designed to support managing TMS assets. These processes range from daily activities, such as device maintenance, device monitoring, and asset performance measurement, to processes with longer time frames. Examples of the latter may include feasibility studies, State transportation improvement plans, congestion management plans, transportation asset management plans (TAMPs), and TSMO plans. Considering the integration of CM into each existing process or plan associated with managing TMS assets can be beneficial to an agency. Incorporating CM into existing processes, procedures, techniques, and tasks enhances an agency's ability to plan for and implement specific improvements to its TMS. Many agencies have an existing CM process or program with the potential to provide benefits for managing TMS assets. However, an existing program may not include documenting the configuration and performing change control for TMS assets.

CM supports TSMO asset inventory management through the systematic documentation of changes. When fully integrated into data management efforts, CM provides information for evaluating TMS asset conditions and performance. A historical record of TMS asset information can help an agency evaluate and monitor its assets and prepare for any potential impact of changes on asset condition or performance. The CM process has several components, as depicted in figure 8. The components and their importance in the process are presented in more detail in the following sections.



Source: FHWA.

Figure 8. Diagram. CM process (Smith 2003).

CONFIGURATION IDENTIFICATION

The concept of configuration identification involves documenting and labeling items in the system, including hardware, software, documents, and the created CM plan. The goal of this step in the process is to assign a unique identifier to each item to track all changes to the item. This process allows agencies to track items more easily as the items are changed, which enhances traceability. Tools agencies may want to consider when implementing CM include spreadsheets, full databases, or more complex software tools. Key factors important to implementation include the presence of a centralized authority, who determines the configuration items and the information collected to provide a more standardized system.

CHANGE MANAGEMENT

Change management, or change control, "is the process of assessing the impact of a possible change to a system, determining the fate of the proposed change, executing the approved changes, and ensuring that the change is carried through to the proper documentation" (Smith 2003). A change control board usually reviews and approves change requests. The objective of change management is to determine the effect of the change being proposed on the entire system and decide whether to proceed with the change. If the change is approved, documenting the change itself and reflecting on the changes to the configuration item's documentation is important.

A potential benefit of change management is the ability to evaluate each change in relation to its impact on the entire system, not just to the subsystem being changed. One example of a change management tool is a version control tool, which allows only one user at a time to check out a version and compare versions for incompatibilities. During implementation, establishing a change control board composed of representatives from different departments may be valuable to ensure a diverse range of perspectives is considered.

CSA

CSA is the process of ensuring all documentation and change history information about configuration items is up to date for the items' entire lifecycles. Potential benefits of CSA include creating the methodology needed to update the documentation to ensure the latest configuration is reflected in the configuration identification database. The aim of CSA is to provide stakeholders and decisionmakers with the most up-to-date configuration information possible. Issue tracking tools are an example of tools used for CSA. These tools document changes as the process moves from approval to completion. For TMS assets, CSA may be connected to TMS asset data quality and data governance. Many TMS assets are composed of exchangeable components. Replacement of any individual component may impact the performance or expected lifecycle of an asset. CSA, supported by data governance policies, can help guarantee the ability to collect and store accurate configuration statuses for each TMS asset.

CONFIGURATION AUDITS

A configuration audit is the process of analyzing and verifying that the configuration item's documentation correctly reflects the current asset status. One of the process goals is to prevent the need to revisit inaccurate documentation caused by incorrect change documentation or lack of prior change documentation. As a potential benefit, this process verifies that changes were executed as approved by the change control board, and the item documentation reflects the current configuration. This process provides the ability to make future changes to the system more efficiently and with more confidence. Examples of configuration audit tools are document management tools, which make archiving and locating files easier and quicker, and issue tracking tools. A key aspect during implementation includes performing audits on a regular basis to ensure CM policies are being implemented.

Implementing CM

CM can be applied to all types of TMS assets and resources, such as hardware, software, field devices, and communication systems, and to documentation, such as policies and procedures. The significance of using CM may include the following:

- Ensuring documentation (requirements, design, test, and acceptance) is accurate and consistent with the actual physical design and installation of a component, device, or item.

- Ensuring project traceability, which is documenting how and why the system is in its current state.

Benefits agencies may experience when applying CM to their asset inventories and documenting system changes include the following:

- Improving system maintainability.
- Improving system reliability.
- Improving the ability to establish and assess performance targets.
- Tracking spare asset inventories accurately.
- Sharing information on assets and resources with other processes.

Configuration tasks can be integrated into all activities, contracts, and services related to TMS assets, such as maintenance, repairs, procurement of new devices, software updates, and changes to code. This integration can potentially help institutionalize CM into existing practices. For example, CM of routine maintenance activities might take the form of inspections conducted on predetermined schedules, where specific items are consistently inspected. During asset repairs, CM may ensure the impact on the entire asset is taken into consideration, which prevents potential adverse impacts on other components of the affected device. CM of services, such as software updates, can also be treated similarly, ensuring that changes made to one specific section of code do not affect other sections of code that control existing software functionality. A thorough CM plan can capture the interdependencies of each software feature and function, improving overall TMS efficiency.

The following stakeholders may be involved in the CM process:

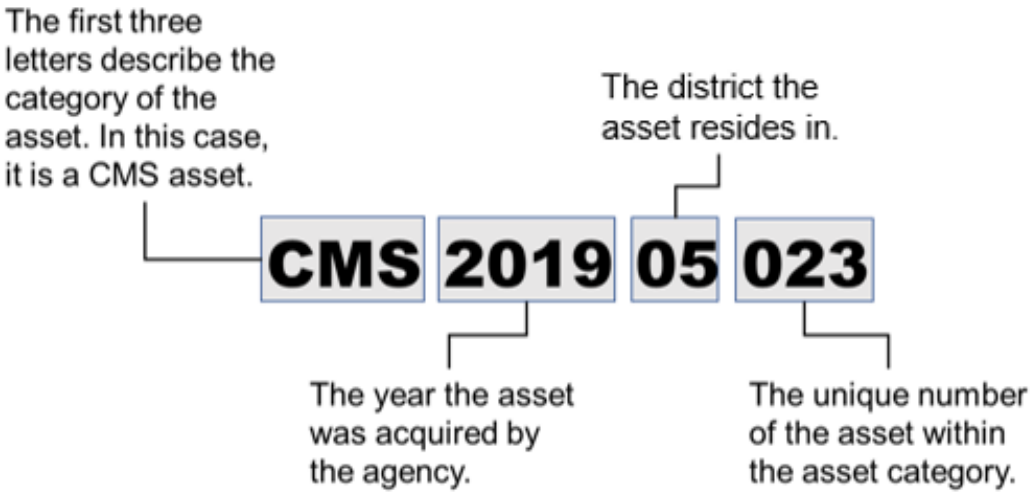
- CM manager, who oversees the CM program.
- CM facilitator, who is typically a consultant with prior CM knowledge.
- Configuration control board members, who are project stakeholders.
- Project managers.
- IT staff.
- Document specialists.

INITIATING THE EFFORT

Agencies wanting to better control changes to their systems and doing so in a consistent manner may consider adopting CM. CM has several components: configuration identification, change management, CSA, and configuration audits (Smith 2023).

A CM plan is a tool to bring each of these components together. Agencies might initiate the CM process by starting with a CM plan to cover key items, such as personnel, responsibilities, activities, policies, definition of procedures, tools, and administrative meeting protocols. Some agencies may not have formal CM plans. However, they may have informally implemented similar processes without identifying them as CM. Agencies can benefit from first identifying existing practices that can be easily integrated into a CM plan with little disruption.

The configuration identification process refers to the task of creating and maintaining the full documentation of the items being configured. Tasks performed as part of configuration identification include item naming, drawing, document management, information management, and baselining. Agencies may consider starting with a review of unique asset identification procedures. Figure 9 shows an example identification structure for a CMS.



Source: FHWA.

Figure 9. Illustration. Unique asset identification composition (Weatherford et al. 2024).

Change management, or change control, may include identifying the need for a change, analyzing the impacts of change on system documentation, evaluating the proposed change, and incorporating the approved change into the existing system's documentation. Once the change has gone through the entre change control process, the changed item is now part of the system baseline. The Kansas IT Office (KITO) is one example of a change management and change control process. KITO's 2021 procurement of a new ATMS went through the agency's CM policy (KITO n.d.).

The KITO change management process requires entering the following details into a form (State of Kansas 1998–2008):

- Project information.
- Description of proposed change.
- Type of change (e.g., system change or procedural change).
- Justification for the proposed change.
- Impacts of not implementing the change.
- At least one alternative approach to the proposed change and any potential impacts of the alternative approach.

- The configuration items affected by the proposed change.
- Impact on cost, schedule, and resources.
- Approval or rejection of the proposed change and the reasons for approval or rejections.
- Dates of the proposal, acceptance, or rejection.

CSA involves documenting all information about items being configured as the system changes. As part of this process, agencies update any asset documentation to reflect the most recent changes and document the asset's current configuration. Configuration audits analyze and verify that configuration items and their documentation reflect the current situation, and that changes were carried out as approved by the administrative body. This auditing adds an extra layer of quality by verifying correct implementation of any identified changes. Agencies use change control to help ensure change is implemented in an orderly and controlled way.

A configuration audit is the process of reviewing and verifying the accuracy and completeness of configuration items and their related documentation. This process ensures the information is current and up to date and helps to maintain the integrity of the CM process.

SUSTAINING THE EFFORT

This section discusses current practices, gaps, and lessons learned in sustaining CM programs and plans for TMS assets and resources. Considering the level of effort and cost involved in sustaining CM programs and plans is important. Agencies must balance the ability to strategically handle system changes with the amount of resources required to implement the CM procedures and processes.

Few of the States interviewed appeared to have existing policies or procedures related to CM. VDOT provides an exception. VDOT acknowledges the importance of CM and has taken measures to incorporate CM into its asset management process. Almost every change to the software product VDOT uses must go through a change management workflow with approval, because keeping the system updated is key. Both VDOT and the contractor are responsible for CM. Those roles and responsibilities are documented in VDOT's internal guidance documents, titled *ITS Change Management Guide* and *The ITS Change Management Guide ITSM Contractor.* Both documents discuss change management roles, change management workflows, change registers, change requests, and overall use of the tool. VDOT was initially hesitant to embrace CM; however, after VDOT had enacted the process awhile, the agency was thankful CM was part of the process. VDOT considers CM to be a key part of its inventory process. Understanding the value of CM to the agency played a role in VDOT's willingness to sustain the effort.[16]

A survey conducted in 2000 provided insight on factors agencies consider when deciding which items to maintain as part of their CM practices: In general, the larger the system managed by the agency, the more likely the agency was to use CM (Smith 2003). Also, among the agencies surveyed for this report, CM was more commonly used by agencies to manage TMSs and less

[16]Interview with, VDOT staff member, 2021.

commonly used in signal control systems. Agencies were more likely to use CM if their system used custom software, as opposed to off-the-shelf software. Information that agencies provided in interviews pointed to a need for improved formal CM training opportunities, since only a small number of practitioners had received formal training on the topic.

MDOT SHA had no capacity to conduct remote device configuration, restricted mostly by limitations on communications with field devices. All configuration activity required dispatching staff to individual device locations, with all configurations done manually on site.[17]

At ODOT, configuration data are obtained from the TMS asset inventory and used by its ATMS. ODOT maintains information on how devices are currently configured and how devices should be configured. Training documentation can be important to ensure new staff can be trained on what tasks are necessary for managing the TMS assets. The documented reports help ODOT determine future operations and maintenance funding and new capital TMS asset replacements.[18]

USING THE INFORMATION

The information used for CM allows agencies to efficiently operate their TMSs on a day-to-day basis. Proper CM supports effectively managed TMS assets, which, in turn, support TMS planning. This section provides examples of how CM results can be used in TMS plans and processes and discusses challenges agencies face in relation to CM.

The effective use of CM involves incorporating the results into existing agency processes. This incorporation leads to reliable data that can be used in TMS plans and processes, such as TMS programming, procurement, and evaluations. CM can be integrated into TMS programming processes, such as upgrading cellular modems, to identify which assets need to be upgraded in the future. The procurement and implementation of TMS assets benefits from the complete change log that becomes available through CM, ensuring accurate accounting. TMS evaluations and reporting are also improved by understanding the condition and performance history of TMS assets over time, as individual changes to one asset may impact the performance of another.

Agencies may want to consider several challenges related to CM. For example, CM must be implemented as early as possible in the system development process and continue the process through the system's lifecycle. Another challenge is the investment in time and capital needed to initiate and continue the process. Table 6 lists these challenges and discusses opportunities they can lead to, as well as mitigation strategies.

[17]Interview with MDOT SHA staff, 2021.
[18]Interview with ODOT staff member, 2021.

Table 6. CM challenges and issues.

Challenge/Issue	Likelihood	Severity	Opportunity/Mitigation
Establishing change control boards; many agencies are unfamiliar with change control boards, their importance, and the process that surrounds them.	High	High	Gain support from upper-level management; use real-world examples of change/configuration control failures and how costly they were to agencies.
Developing the correct CM processes.	Low	Medium	Create a thorough CM plan that considers all required resources, policies, and tools.
Following CM process and procedures.	Medium	High	Prioritize a configuration verification and audit process to improve QC and identify opportunities to improve procedures.
Staffing for TMS configuration.	High	High	Identify opportunities to embed individual tasks into existing responsibilities and processes; include resources as part of a larger TMS support plan.
Motivating staff to develop and correctly configure assets (i.e., getting staff to realize the true importance).	High	Medium	Share results and benefits with the entire team in a clear, concise, and consistent manner.
Increasing the speed of user acceptance.	High	Medium	Ensure tools are easy to use and only the necessary steps are being introduced into each process.
Encouraging implementation as early as possible in the system development process.	Low	Medium	Identify steps in the development process where the CM effort can be initiated; update any formal procedural documents.

CHAPTER 6. MANAGING TMS INVENTORY AND RESOURCES

The purpose of this chapter is to discuss the management of a TMS inventory and resources, with a focus on how agencies plan and implement their TMS inventory to realize desired outcomes. Effective management involves extracting the most value from the inventory with respect to fulfilling agency obligations. This chapter reviews how agencies have set up the systems, processes, and procedures to manage TMS inventory and resources. Additionally, the chapter discusses organizational roles and responsibilities, support activities, and steps to embed the TMS inventory management process into other agency activities.

Managing assets focuses on the reliability, health, and performance of assets; the assets' needs; and the activities, practices, and resources that help ensure the assets meet agency expectations. Managing assets includes ensuring processes and procedures are appropriate, organizational roles and responsibilities are clearly defined and fulfilled, and the necessary resources are secured to operate and maintain the program. Managing a TMS inventory involves applying the right resources to get a system up and running, keep it running, and ensure the system can be used effectively. Managing a TMS inventory means putting in place and monitoring the mechanisms to inform and support day-to-day activities related to TMS assets.

This chapter builds off previous chapters describing the value of TMS inventory actions. This chapter examines the driving forces behind the development of an inventory process and the steps the interviewed agencies have taken to implement processes and procedures and assign responsibilities for completing them.

INITIATING THE EFFORT

Addressing Goals and Objectives for Managing TMS Assets

Agencies often develop asset inventories because they recognize the need to provide a full accounting of expenditures—past, present, and future—related to TMS assets. They also see a need to effectively conduct LCP for maintenance, replacement, and extension of function across the network. This process involves ensuring the right information is gathered to confirm asset configuration is up-to-date and to monitor asset health and operational status. Agencies may consider evaluating the various asset types, technologies, and functions to ensure the information gathered contributes to the TMS management goals and objectives.

Forming and Nurturing Stakeholder Relationships

Effectively managing TMS assets involves ensuring that all the agency organizational units that rely on, interact with, and bear responsibility for the proper function of the assets understand and execute their roles in ensuring the inventory, configuration, and documentation are maintained. How to keep the information in an inventory current may be obvious to the staff with primary responsibility for managing TMS assets but may be less obvious to units within the organization with narrower responsibilities. For instance, a maintenance unit will understand its responsibility to execute work orders to repair or upgrade assets. However, this unit may not fully appreciate the influence this work may have on keeping an inventory of TMS assets current. When the maintenance team has access to reliable information about the proper software or firmware configuration for the specific asset, the team is not only enabled to execute a work order quickly and definitively but also to more efficiently plan work to accomplish known tasks. If the team is headed to the field to configure a device with a software upgrade, it can access the inventory to see whether other assets in the area require a similar upgrade and perform those upgrades on the same trip.

Agencies may consider extending this concept to all organizational units and the functions they perform to manage TMS assets. Collaboration that considers and coordinates a broad array of agency functions will benefit all parties. This collaboration can pave the way for better inventory quality, more consistent asset CM, and more comprehensive documentation across the enterprise. This collaboration supports sharing needs, priorities, and a common understanding of how the actions of each part of the organization can benefit the others. These relationships are fostered not only at the leadership level but also at the line or functional level to be effective and durable.

Engaging decisionmakers and managers will support the appropriate allocation of funding and staff resources; meanwhile, discussions with field staff can help identify concerns, ideas, and feedback for managing TMS assets.

Assigning the Proper Resources

Assigning the proper resources involves getting the right organizational entities and staff in place and ensuring they have the necessary tools and resources to gather and maintain inventory data. Agencies can communicate the value of the effort to gain organizational commitment and then deliver that value for the organization to continue supporting the effort.

In this process, agencies can identify key personnel from various departments, who can contribute to the process of managing TMS assets. This personnel may include staff from maintenance, procurement, IT, and other departments. By fostering cross-functional collaboration, agencies can potentially enhance the effectiveness of managing TMS assets. Providing training and resources for staff involved in the process can empower them to make informed decisions and complete tasks more effectively. Ultimately, agencies may find it beneficial to continually evaluate the resources assigned, ensuring the right personnel are in place to support the ongoing management of TMS assets.

Monitoring the Quality and Completeness of Inventory Information

Agencies may want to consider revisiting inventory information on a periodic basis. After the information is assembled, confirming that the tools, processes, and procedures for gathering and storing the data are current and functioning properly and that the personnel responsible for capturing information are following protocol is important. This practice includes revisiting inventory compilations the agency created before the introduction of a specific, focused effort to manage TMS assets.

To achieve this goal, agencies can explore implementing regular audits of their inventory data, as well as updates to their data collection processes, as needed. This process may involve evaluating the data to identify any gaps or discrepancies. Agencies may also want to consider establishing performance measures to track the progress and effectiveness of their inventory management processes.

Identifying and Evaluating Performance Trends

Performance trend analysis serves at least three important priorities. The first priority is to plan scheduled maintenance activities to keep assets functioning properly. The second is to forecast the end of service for assets. This process allows for more accurate programming of replacement funding. The third is to hold contractors contractually accountable for SLA performance. In each instance, this information is key to justifying budget allocations.

Effectively managing a TMS inventory of assets may involve an understanding of the gaps that exist between current capabilities, future needs, objectives, and the needed organizational commitment. Improvements to enhance or sustain an inventory of these assets may include using information management systems, processes and procedures, and tools.

Questions that agencies may want to address when planning an inventory of TMS assets include the following:

- Are the needs associated with TMS inventory management clear and understandable? Examples are as follows:
    - Can a clearly defined need for the overall program be communicated to the staff tasked with capturing and maintaining the information?
    - What needs to be included to ensure intra- and interorganizational support?
- Has the agency defined all the important information to include in an inventory of assets so that the TMS program goals and objectives can be met? Examples are as follows:
    - Are all the data points necessary? Do they align with program goals?
    - Can the elements be directly aligned with one or more goals or objectives?
    - Have the necessary resources been identified to capture, store, and access the information?

    - Does the agency already have an inventory of TMS assets? What information is included in the inventory, and does it support the TMS program goals or objectives?

- Are current systems suitable for managing TMS inventory, or more specifically:
    - Are they capable of capturing all the necessary data?
    - Is the information stored in a secure, reliable database that can be easily accessed by those who need it?
    - Is the user interface intuitive and clear enough for staff to easily enter all necessary information free of error?
    - Is the level of automation sufficient to keep the level of effort manageable so that staff use the tool as intended?
- Whatever system the agency has identified, selected, or procured to support TMS inventory management, does the system possess the following:
    - Appropriate technical specifications?
    - Enough capabilities to enable staff to satisfy roles and responsibilities?
    - Acceptable levels of standardized processes and procedures?
    - A user-friendly interface?

As part of the process, the agency may want to consider the cost to obtain, set up, and operate the system. The agency representatives interviewed for this project most often indicated that the main goal for developing and maintaining a TMS asset inventory was to gather support for the resources necessary for operations and maintenance of the transportation network. In some locations, this goal was specifically included in jurisdictional TSMO directives. In other instances, the agency implementing the inventory was tasked less formally.

Interviews of several agencies captured some of the driving factors for developing and maintaining a TMS inventory. Caltrans staff indicated there are requirements to provide statistics on asset status and health and pointed to legislation requiring that Caltrans monitor TMS and ITS asset health.[19] Lake County, IL Division of Transportation staff stated that knowledge of systems and assets supports pursuit of funding for projects, and integration with geographic information systems (GISs) provides a spatial understanding of the universe of transportation assets (not just ITS and signals). Staff in Lake County generate a monthly report on system statistics and system health that is shared departmentwide.[20] The staff uses the data to track vendor compliance with SLAs, which is also a priority for TDOT and VDOT TMS inventory management.[21,22]

[19]Interview with Caltrans staff member, 2021.
[20]Interview with Lake County, IL, Division of Transportation staff member, 2021.
[21]Interview with TDOT staff members, 2021.
[22]Interview with VDOT staff member, 2021.

MDOT SHA staff stated that current agency policy is focused on maintenance support for existing assets, but that ITS is becoming more common and more relevant to decisionmakers. MDOT SHA is looking to update policies and procedures in conjunction with a long-standing asset management program to remove error and guesswork.

At MARC, lack of funding is a big issue. Tracking deficiencies is important to support needed investment in TMS assets and is necessary to support a technology plan to replace components as they age and plan for a 2-yr budget cycle. Overall, TMS inventory management is considered necessary to move from a reactive, failure-based asset approach to a proactive, planning-based approach.

At ODOT and Nevada DOT (NDOT), significant emphasis is placed on ITS/TMS asset management within TSMO. At ODOT, asset reports are used for project planning and an annual programming report to the transportation commission to support funding and programming. At NDOT, TMS inventory management is important for establishing performance dashboards, conducting preventive maintenance, keeping everyone focused on performing their jobs effectively, supporting staffing needs, and generating supporting documentation for budget requests (FHWA 2022).

SUSTAINING THE EFFORT

Sustaining TMS inventory management requires that processes and procedures implemented for the effort are followed, and, where necessary, adjusted to adapt to changes in TMS assets, programmatic priorities, and resource constraints. Considering these measures as they relate to the full scope of activities related to managing TMS assets is important (figure 3).

Managing the TMS inventory requires that each element in the diagram is considered and adapted as the initiative matures and evolves. Some examples are as follows:

- Asset inventory: As the types and amount of TMS assets grow and diversify, the tools and people integral to sustain the effort may also need to change to gather new data, arrange and collate information differently, and provide access for new staff or groups of staff.

- Asset condition: New and different asset types introduce the need to reexamine how condition is assessed and reported. Additionally, evolving agency needs that drive upgrade and replacement decisions must be accommodated.

- Asset data maintenance: As new assets are brought into the inventory and older asset classes age out, the underlying data can be expected to evolve to capture the needed information for these new assets. This need to add new data can drive the need to modify the systems, components, and software applications that enable storage and retrieval of this information in the inventory.

- Asset data management: As new assets are brought into the inventory and older asset classes age out and as new tools to support TMS inventory activities are developed and implemented, the systems that store the data and make it accessible to users must be maintained and updated to keep pace.

- Asset spares: The need for and management of asset spares must be revisited on a regular basis to ensure these needs are relevant. For example, as TMS solutions migrate away from procured hardware toward software-as-a-service delivery models, the approach to managing inventory must also evolve to capture different types of data and support procurement and performance management.

- Asset configuration: The implementation and inclusion in the inventory of more and newer TMS asset classes will correspondingly increase the need to manage a larger number of configurations.

- Monitoring, evaluating, and reporting: As new asset classes are introduced, an agency may need to collect and incorporate additional data into their inventory of TMS assets. During this process of adding data, the asset evaluating and reporting mechanisms also need to use and reflect these new assets in monitoring and reporting.

Agencies implementing programs may find that creating an inventory management program that is initially perfectly suited to meet all needs is challenging. Even extensive and careful planning can over- or underemphasize various program needs and miss some of the details related to asset inventory. As such, routinely examining the effectiveness of the approach and tools used to support inventory management is important. This practice includes monitoring the quality and completeness of the information gathered, identifying gaps and unmet needs, and reevaluating whether enough or too much information is being captured. As these gaps are identified, adjusting processes, procedures, roles, and responsibilities may become necessary. Reevaluation of resources and their allocations across the organizational functions that support inventory management may also be involved.

Each agency interviewed as part of this study that has implemented a TMS inventory indicated that intraorganizational collaboration is important to sustain a program. Most specifically, coordination among asset managers, operations staff, and maintenance personnel is seen as necessary to define inventory data elements and to capture the information, regardless of the level of sophistication or scope.

Assigning responsibility typically comes down to who needs the inventory information and who has access to the assets. Maintenance staff most commonly have access to field devices, whether they are installed or have been brought into a maintenance facility for repair, configuration, or modification. Assets located in operations centers are more accessible to operations support staff. These operations and maintenance staff are assigned varying levels of inventory management responsibility based on the expectations of the asset owners and the tools and processes in place. Aside from that general practice, the agencies interviewed did not identify any systematic approaches to the assignment of responsibility.

Most agencies selected or developed their tools based on a combination of operational needs and programmatic necessity related to specific requirements. Some agencies took an analytical approach to tool development; meanwhile, others followed a more organic approach and adapted an existing tool.

USING THE INFORMATION

Effectively using the information gathered is crucial to realizing the value of the effort to initiate and sustain the TMS inventory. Accessing and using the inventory where consistent use of this information can potentially be leveraged to evaluate and provide a basis to explore possible improvements is vital. If the appropriate level of intra- and interorganizational coordination is carried out at program initiation and implementation—and the tools and processes address the program goals—then integrating these goals into daily asset procurements, upgrades, and maintenance activities can further promote success.

Agencies can use the data to identify and evaluate performance trends and plan for lifecycle and growth planning. The following facets can be considered:

- Performance objectives—The alignment of investments with an agency's strategic priorities, including asset condition and minimum acceptable performance as examples.
- Preventive treatments (i.e., maintenance/upgrades) over the lifecycle of an asset—A comprehensive LCP analysis process to determine the most cost-effective approach based on performance data.
- Deterioration models—The application of analysis or performance models that reflect changes in asset conditions with and without preventive maintenance.
- Desired conditions—A desired network-level state of repair that represents the performance desired for each asset class.
- Targeted conditions—The setting of interim targets that reflect time-constrained achievements.

Researchers asked agencies that had implemented TMS inventory management about managing the day-to-day use of the information (table 7).

Table 7. Agency inventory information use summary.

Agency	Information Uses
NDOT (FHWA 2022)	Working toward implementing outcome-based performance metrics for project implementation from master plans (TSMO, ITS)—overall goals and objectives (e.g., safety, reliability).
Caltrans[23]	Developing an annual factbook, which includes an inventory of asset information that contains lifecycle data, used to determine projects and funding.
Lake County, IL, Division of Transportation [24]	• Sharing information is necessary to support pursuit of funding for projects. • Integrating with GISs can allow other entities to gain a spatial understanding of the universe of transportation assets (not just ITS/signals). • Monthly reports on system statistics and system health are shared departmentwide. • Data are used internally for planning purposes.
MDOT SHA[25]	• Senior finance managers are currently the audience. • The information is currently only used within the division chief level in the ITS division. Additionally, TSMO planning projects occasionally request some fiber and technology resources, such as DMS information. • Part of the new asset management office currently being established will expand future data users.
MARC[26]	• MARC wants to use the information to predict the costs of its spending each year for its networks. The technology plan has afforded MARC a plan to replace components as they age before experiencing increases in maintenance and repair costs. MARC received funding from the statewide transportation plan and local money, so it needs to be able to estimate costs for maintenance and repairs of assets 2 yr or 3 yr into the future. The presence of the inventory and the ability to assess asset condition information and costs for maintenance supports estimating these needs for funding. • Very few people can modify the data in the inventory of TMS assets.

[23]Interview with Caltrans staff member, 2021.
[24]Interview with Lake County, IL, Division of Transportation staff member, 2021.
[25]Interview with MDOT SHA staff members, 2021.
[26]Interview with MARC staff member, 2021.

Agency	Information Uses
ODOT[27]	Asset reports are used for project planning, in the annual programming report, and for reporting to the transportation commission.
TDOT[28]	• At one point, device uptime had suffered a bit, so management wanted to know that systems were performing. The agency staff are well-supported by management. • Device uptime is reported daily and weekly, and all that data go into monthly reports. Staff in the traffic operations office puts out quarterly statewide performance reports. Staff are also responsible for the daily failure reports; the four regional IT team leaders go through the reports weekly, run a snapshot, and report weekly failures. Additionally, staff in the traffic operations office compiles and publishes a quarterly report of statewide asset performance, including a pie chart and six pages of analyses of devices and their performances. • Performance metrics vary per device, based on historical data with regard to mean time between failure and average repair time on a particular device type. Devices that tend to have the least failures and the highest visibility are the most highly valued by the agency. • Some of the performance metrics are tied to the TMC manager's performance metrics. The ITS device performance has a tie-in to the device's individual performance metrics unless mitigating circumstances exist. • A limited number of people can access databases and enter information. Staff uses the tools that are available to measure against data entry and reporting and check for any errors made.
VDOT[29]	VDOT desires to take a more fiscally based approach to support managing and monitoring TMS asset condition. VDOT is initiating a process to expand on what information is included, compiled, and reported on maintenance and repair work orders.

[27]Interview with ODOT staff member, 2021.
[28]Interview with TDOT staff members, 2021.
[29]Interview with VDOT staff member, 2021.

Common themes include the following:

- Knowing the audience—Not only being aware of the data that needs to be collected, but also what information needs to be summarized for monitoring and reporting purposes.

- Managing performance metrics—Evaluating whether the right information is being gathered and interpreted appropriately.

- Emphasizing planning—Applying and adjusting planning to ensure the information needed to support incorporating information on the condition of TMS assets into TMS planning and programming processes or activities is available.

- Remaining consistent—Implementing regular periodic reporting and feedback mechanisms to sustain momentum and solidify value.

LESSONS LEARNED

The agencies that supported this study offered lessons learned, which are listed in table 8. The following are among the more frequently cited lessons:

- Having clear direction—Staff charged with capturing and using the data need specific instructions to ensure procedures are followed.

- Focusing on essentials—Several agencies indicated that data captured should be limited to only what are necessary, and data sets should be reviewed periodically to eliminate unnecessary requirements.

- Ensuring data quality and currency—Inventory data need to be constantly validated and consistently updated; stale or inaccurate information is not useful.

- Supporting and nurturing—Intra- and interorganizational support need to be maintained to retain buy-in.

- Evolving and adapting—Processes and procedures need to be reviewed for continued relevance, particularly as the assets evolve and the inventory changes.

- Managing resources—Inventory management and maintenance are not typically within the job descriptions of those people tasked with doing it; data management is different from system or device management and requires staff be given the tools and time to perform it; communications with staff about the importance of inventory management is key.

Table 8. Agency lessons learned.

Agency	Lessons Learned
Caltrans[30]	• Managing TMS assets is a relatively new idea. • Resources can be an issue at the district level (i.e., not enough to keep up). • The agency should have started this effort earlier. • Headquarters must provide clear direction to districts. • Staff must submit a standard subset of data. • Clear policy in a common, clear format is needed. • Definition of data sets (e.g., what is working and not working) is needed. • Policies to track things (e.g., construction and maintenance) are needed. • More work and focus on district buy-in is needed.
Lake County, IL, Division of Transportation[31]	• The biggest lesson learned is that if data are not updated, the data are useless. • Only keep what data are needed. Too much data are available to keep everything; only keep what data are necessary and important to reference later. • Be prepared to evolve over time. What data are needed are going to be different 5 yr from now. Knowing what information may be needed years from now can be tricky. The only thing agencies can do is talk to other groups and see what information is needed. • No one solution fits all, so agencies just have to get close and develop whatever they can in-house, as long as they are able to update/maintain as needed. • The technology is changing rapidly. Lake County has eight different types of detection on their system, all managed differently. Maintaining all of the types and their data becomes challenging.

[30]Interview with Caltrans staff member, 2021.
[31]Interview with Lake County, IL, Division of Transportation staff member, 2021.

Agency	Lessons Learned
MDOT SHA[32]	• Additional technology for automated notification of failures/issues is useful. • Daily/weekly operational status checks are important and allow focus on problem areas and event support. • Contractual support is important; labor shortages can cause shortfalls (physical troubleshooting and repair, help desk support). • Program management and repair staff are not really data managers. Experience and specialization gaps must be accommodated and cause information gaps. • Linking in the unique issues to consider for different assets early in the procurement process is key, as the incorporation of these issues may ensure the timely acquisition of devices and support. • ITS often falls within either the maintenance office or the operations office at State DOTS. Pros and cons exist for each. Technology maintenance needs strong leadership but is often not well understood by either office, as its focus is slightly different in each case. • Procurement for contractual support for ITS must be managed by someone experienced with effective practices in ITS.
MARC[33]	• When MARC changed the radio system, they spent time trying different products and found all the products contained surprises. • The early identification of issues and processes to respond to maintenance and repair issues support timely response and resolution. • More formal documentation of what to inventory and how to incorporate changes is needed. • Establishing inventories of TMS assets can be accomplished, however keeping the information current presents challenges. These challenges stem from incorporating information based on maintaining and repair activities into the inventory. Maybe this process can be made easier via a ticketing system on phones or on devices used by staff in the field. • Collect only what data are needed.

[32]Interview with MDOT SHA staff, 2021.
[33]Interview with MARC staff member, 2021.

Agency	Lessons Learned
	• Many issues may be included and monitored in an inventory of TMS assets.
ODOT[34]	• A separate, unintegrated TMS is doomed for failure. • A TMS should be integrated in some way with other systems. • Staff must realize and understand the benefits to use it. • A TMS inventory and maintenance management system may help to address challenges for staff to see and understand the benefits of this information and capabilities. • Data accuracy is a magic question for managing TMS assets. • Training should include a QA and QC process. • Focus on what information the agency really needs to inventory, monitor, and use. • Develop clear procedures. • A QA procedure is needed.
TDOT[35]	• Try to avoid disparate systems that are going to be difficult to integrate down the road. Think ahead; think about fully integrated systems that will easily communicate with each other. • Collect only necessary data.

[34]Interview with ODOT staff member, 2021.
[35]Interview with TDOT staff members, 2021.

CHAPTER 7. MAINTAINING TMS INVENTORY AND RESOURCES

The purpose of this chapter is to highlight the process of maintaining a TMS inventory and resources to ensure their ongoing value and effectiveness. As highlighted in the agency interviews from the previous chapter, a TMS inventory can provide ongoing value only if the information within it—along with the supporting tools, processes, and procedures—are properly maintained. Maintenance ensures the information stays current, remains accessible for use, and thus continues to meet agency needs. A configuration maintenance program has multiple components that include a full range of mechanisms and resources to ensure the TMS inventory is appropriately updated and integrated into future activities and contracts.

Maintaining the configuration of an inventory of assets and resources helps ensure that agencies can follow management processes to meet TMS program needs. These maintenance activities also ensure that the mechanisms remain in place to capture, store, and provide access to TMS asset data and information on other resources. Chapter 5 of this report discussed the processes and practices employed for CM of TMS assets. This chapter provides insights into actions an agency can consider to ensure that their tools and techniques support the evolution of the TMS assets in the inventory.

INITIATING THE EFFORT

Configuring field assets, which involves implementing and documenting the proper code, firmware, hardware, and other related components, is a key part of managing TMS assets. Ensuring that these elements remain up to date and adapting them to meet evolving TMS requirements contribute to continued operational functionality and can potentially extend an asset's useful lifecycle. To accommodate or adjust to these evolving changes, any tools and associated processes in use must be flexible to support these expected future adjustments.

During changes to TMS assets and resources, the staff tasked with supporting the TMS inventory effort can be given the following information and tools to adapt to these adjustments:

- Understanding of the need for the changes.
- Information about how these changes affect what needs to be done.
- Specific direction on the actual asset configuration changes and how and where they are to be deployed.
- Updated processes and procedures detailing how the changes are to be implemented.
- Any necessary inventory system updates, including changes to user interfaces.
- The necessary resources (i.e., funding, staffing, tools, etc.) to execute the configuration and inventory updates.

Agencies may want to consider that inventories of TMS assets and resources may need to change as TMS assets grow in number, quantity, complexity, and geography. Where possible, future inventory needs are considered when selecting and developing the initial inventory and when selecting software and providing interfaces (system and user) and data storage options.

The agencies that participated in this study implemented a wide range of systems for TMS inventory maintenance. Agencies that were still early in the TMS inventory process developed spreadsheets or other simple database solutions, and most had not considered more comprehensive solutions necessary at that time. Agencies that had more experience inventorying were investigating next steps and associated system upgrades. Agencies that had maintained TMS asset inventories for longer periods or agencies with large asset inventories, had procured commercial-off-the-shelf or relied upon custom-developed and maintained tools. Table 9 summarizes these agency approaches.

Table 9. Summary of current agency approaches.

Agency	Current Inventory Tool	Future Considerations
Caltrans[36]	Products used are developed by headquarters and individual districts.	• Global transportation asset management system. • Brand of server.
Lake County, IL, Division of Transportation[37]	Mix of internally developed and contractor-provided.	Nothing new on the horizon.
MDOT SHA[38]	Spreadsheet-based tool and summary prepared by prior staff.	• Developing more extensive approach. • Exploring options to add mapping and configuration data.
MARC[39]	Spreadsheet and database tools developed by in-house staff.	Nothing new on the horizon.
ODOT[40]	Purchased products modified by ODOT staff and incorporated into the TMS.	Focus on training.
TDOT[41]	Spreadsheet and database tools developed in-house.	Adding identity services engine.
VDOT[42]	Tools provided by contractor.	Transitioning from legacy asset management software.

[36]Interview with Caltrans staff member, 2021.
[37]Interview with Lake County, IL, Division of Transportation staff member, 2021.
[38]Interview with MDOT SHA staff members, 2021.
[39]Interview with MARC staff member, 2021.
[40]Interview with ODOT staff member, 2021.
[41]Interview with TDOT staff members, 2021.
[42]Interview with VDOT staff member, 2021.

Agency staff indicated that evolution and possible replacement of existing tools may become necessary, but these upgrades appear to be looked on as something that can be done as needs change and scaling becomes necessary.

SUSTAINING THE EFFORT

Sustaining TMS configuration requires that processes, procedures, and tools for CM are monitored for quality, timeliness, and integrity. This section discusses current practices, challenges, opportunities, and trends relating to maintaining TMS inventory and resources, including how a TMS inventory is maintained over time.

By definition, a TMS inventory is only relevant and valuable if the data contained in it are accurate and free of error. Managing and maintaining an inventory of TMS assets and resources involves providing the needed resources, staff, TMS capabilities and resources (e.g., tools) are available to manage and ensure the inventory if current. The range of activities, tasks, and resources agencies may need to manage these inventories may include the following:

- Data QA and QC—Require that data are checked for accuracy and completeness at the point of capture and at the point of entry into the chosen data management tool.
- Data governance—Summarized as the mechanisms that control access to inventory data and ensure data are properly stored and routinely backed up.
- Interface management—Involves the maintenance of interfaces used to import or enter data and distribute them to authorized points. Includes the use of appropriate information security standards and the verification of data integrity through regular audits.
- Database management—Includes the procedures and tools used to ensure the databases are maintained with current software and firmware configurations, licenses, and hardware specifications.

The agencies that contributed to the study indicated that TMS inventory maintenance activities typically do not follow any special processes. The agencies noted that activities mostly rely on existing basic database functionality. Access to tools and stored data generally appears to be aligned with agency information security policies. None of the agencies used tools specifically designed for TMS configuration maintenance.[43,44] Researchers did not identify whether agencies used any particular data management plan or processes. These conditions reflect the modest level of agency capabilities and resources available to manage the inventories of TMS assets and resources.

CURRENT PRACTICES

The research team asked the agencies about their current practices and procedures regarding database management and data governance. Table 10 highlights some of these practices.

[43]Interview with Caltrans staff member, 2021.
[44]Interview with Lake County, IL, Division of Transportation staff member, 2021.

Table 10. Examples of current agency database management practices.

Agency	Database Management	Data Governance
Caltrans[45]	Headquarters and the individual districts manage the database.	The Caltrans IT department covers data governance (e.g., backups).
Lake County, IL, Division of Transportation[46]	Lake County manages the data in the databases and device management system.	• All data are backed up by various systems, not one central backup. Lake County is working on a device recovery plan that will be implemented in 2021. • Access to the systems is possible via virtual private networks and various levels of permissions granted to staff. Staff do not manage the data directly but instead use the associated resources, such as cameras and signal data.
MDOT SHA[47]	Combination—ITS division manages or oversees; prior data manager left; position is vacant and has not yet been filled.	Record retention for asset data information is 5 yr for assets procured using State funding and 7 yr for Federal funding. However, the agency retains data for specific devices if they remain in service for longer periods of time.
MARC[48]	Need to address.	• Only two or three people can make changes. • Documentation is primarily practiced when someone leaves. Have not seen the need to expand.

[45]Interview with Caltrans staff member, 2021.
[46]Interview with Lake County, IL, Division of Transportation staff member, 2021.
[47]Interview with MDOT SHA staff members, 2021.
[48]Interview with MARC staff member, 2021.

Agency	Database Management	Data Governance
ODOT[49]	• IRS maintenance staff. • Regional electrical staff. • Some other operations staff.	• All enterprise systems are backed up. • Data governance is governed within the data warehouse.
TDOT[50]	• A database administrator is responsible for adding new devices, but numerous parties are able to access information on these devices. The agency uses maintenance tickets and response authorizations when changes may be made to assets. • An inspector from the construction office may perform this role. • An IT person may generate the ticket to allow the appropriate contractor or agency staff to perform needed revisions.	Data entry is limited to certain staff, such as the lead ITS point of contact for the contractor or one of the regional network operations administrators.
VDOT[51]	VDOT has a contractor that manages the inventory and supporting database. If anything has to be changed, the changes are made by the contractor, who is managed by VDOT staff.	• No formal plans were documented. Transitioning to different software tools was one area that needed to be addressed. • Everyone had access, everyone could modify data, and this access was an issue that has since been addressed. VDOT must now complete an approval process to determine staff access levels. • User access is limited, based on staff roles and job functions. However, only one or two people can make changes to the database on the backend. • Very limited on the read/write access. If something comes up in error, can trace to users to troubleshoot.

[49]Interview with ODOT staff member, 2021.
[50]Interview with TDOT staff members, 2021.
[51]Interview with VDOT staff member, 2021.

LESSONS LEARNED

Table 11 highlights the lessons learned by the study participants about maintaining and storing configuration information for TMS assets.

Table 11. Agency lessons learned about maintaining configuration information.

Agency	Lessons Learned
Caltrans[52]	• Ensure guidance documents exist for accuracy. • Perform spot checks on data accuracy. • Ask districts to note when they last configured devices and how. • Provide details on how devices were configured, such as firmware versions, software versions, and device settings.
Lake County, IL, Division of Transportation[53]	• Keeping information up to date is complicated due to multiple systems, lack of access to systems in the field, and varying levels of experience and understanding of system input needed. The agency is in the process of improving information updates from the field using a tool the GIS department is creating. The tool was targeted to go live by spring 2021 and linked to the database. • The agency uses native tools obtained from the system integrator for devices. • Checklists of procedures for device setup and configuration include verification procedures.
ODOT[54]	• Data accuracy is a magic question for managing TMS assets. • Training includes a QA and QC process.
TDOT[55]	• A limited number of people enters information into databases. Using the available tools to measure against any sort of user error is key. • The agency uses commercially available software on computers for version control of spreadsheets. The program tracks who makes changes and will not allow users to make certain undesirable changes on top of other users. Users can also check out and check in documents to control access. • A suite of commercial products are used for performance management and related tasks or activities. Configuration templates are stored, copies are made, and tasks and activities are managed using these products.

[52]Interview with Caltrans staff member, 2021.
[53]Interview with Lake County, IL, Division of Transportation staff member, 2021.
[54]Interview with ODOT staff member, 2021.
[55]Interview with TDOT staff members, 2021.

Agency	Lessons Learned
VDOT[56]	• The agency runs a fiscal cost report at the end of every month, which must line up with maintenance, repairs, and other tasks performed. This report is monitored, tracked, and used as the basis of payment for services. • The agency uses barcodes; every asset gets a barcode that is associated with the asset's serial number in the database. All assets are tracked within the asset management system. • A change management module is in the works to ensure the database is clean and supports a robust system. Almost every single change (even if the change is to the agency's internal change management guidebook itself) must complete a change management workflow with approval. This workflow is key to keeping the system accurate. • The contractor is responsible for change management. All changes run through a change manager, who follows changes through the process all the way to the end, looking for red flags and making sure the change is implemented. The change manager is also responsible for closing out completed work.

[56]Interview with VDOT staff member, 2021.

CHAPTER 8. INCORPORATING TMS INVENTORY INTO TMS PLANNING

The purpose of this chapter is to explore the integration of a TMS inventory into TMS planning, which is key for the effective management of TMS assets. As discussed in previous chapters, the primary motivation for TMS inventory, documentation, and CM activities is to facilitate informed decisionmaking regarding future investments in TMS assets. An understanding of existing assets, their configurations, and their performance is key for effective TMS planning. This understanding establishes a baseline and offers the necessary insights to determine the procurement, management, and maintenance of new assets. This chapter examines how agencies use inventory information to support these priorities.

At this stage, revisiting the agency TMS processes and plans overview provided in figure 1, which presents a comprehensive framework outlining the processes and activities supporting TMS management and operations, can be helpful. This chapter discusses potential links between the TMS inventory and the processes shown in the framework.

Agencies can consider a number of options when pursuing efforts to enhance or develop an inventory of TMS assets and resources. These options may include planning, designing, procuring, implementing, incorporating, testing, and managing efforts to establish and support the use of an inventory of TMS assets. The sections in this chapter outline issues to consider with these different options.

INITIATING THE EFFORT

Acknowledging the need to conduct future investment planning is an important first step. Formulating an inventory framework that supports this step can be challenging. Important aspects in constructing that framework include the following:

- Understanding the potential options (e.g., process, expectations, etc.). This aspect may involve the collection, compilation, saving, and documentation of information.

- Defining goals for TMS assets within the planning framework. This aspect involves defining the expectations for how assets should perform, both individually and as part of the larger TMS network of assets.

- Understanding how the TMS inventory supports planning and investment. This aspect pertains to the importance of what is reported, how it is formulated and summarized, and the degree to which it meets the expectations of decisionmakers. This topic can be further divided into the following areas:

    - Setting expectations for TMS inventory management related to planning objectives and priorities.

    - Developing and implementing output and reporting mechanisms to support planning requirements.

    - Developing methods and processes to accumulate and deliver planning-related output.

To effectively support planning efforts, incorporating the input and feedback of the intended audience into the TMS inventory effort is important. This approach can enhance the relevance and usefulness of the inventory, making it more efficient and effective.

Examining each of the planning components identified in the diagram reveals the following important priorities. Specifically, the agency may develop the inventory in a manner to support each of the following:

- Planning and developing strategic TMS plans: The inventory will need to support the evaluation of benefits and costs associated with asset procurement, maintenance and management through a lifecycle analysis model.

- TMS planning and feasibility studies: The inventory should be constructed and configured to allow for collection of and access to the data needed to support planning and feasibility studies.

- TMS programming, allocating resources, and operations: Resource identification and allocation based on actual expenditures to meet current needs is key to understanding what is necessary to plan for future investment.

- TMS product development, procurement, and building: Inventory data can be very useful for accurately preparing plans for developing, procuring, and building future systems and assets that will be required to implement them.

- TMS monitoring, evaluating, and reporting: Inventory data regarding asset lifecycle costs, condition tracking, and documentation of maintenance and configuration activities are key inputs to evaluation and reporting for planning.

- TMS self-assessment: The full spectrum of inventory data described in this document is necessary for an agency to conduct a comprehensive self-assessment, which is a cornerstone element of a planning program.

SUSTAINING THE EFFORT

By appropriately defining the framework to meet planning needs, the staff who maintain and report on the status of a TMS inventory of assets and resources can help ensure they follow the desired processes. This reporting may indicate the information is current and of appropriate quality and that the reports accurately reflect the information the inventory contains.

Additionally, these activities may involve periodically reassessing or auditing the processes, activities, and tasks that ensure the TMS inventory of assets and resources is current and being maintained. Staff leading the development of an inventory of TMS assets and resources or managing the inventory may want to consider reengaging with end users to determine whether adjustments are needed to what data are saved, how information is accessed, how often asset conditions are reported, and what assets and resources are inventoried.

USING THE INFORMATION

Since the information is gathered to support planning, managers and decisionmakers will find this information useful as they develop investment priorities, which can include the following:

- Modifying preventive maintenance schedules and associated resources.
- Reevaluating lifecycle calculations and associated cost data for asset types and versions.
- Assessing the need for device upgrades, such as software, firmware, and supporting items.
- Providing updated input to the planning process for asset investment.
- Assessing the comparative value of asset upgrade and repair versus replacement.

Agencies may consider using the inventory information to support the processes and activities associated with the management and operation of a TMS. The framework shown in figure 1 includes seven processes that can be followed throughout the lifecycle of a TMS program. The seven processes include the following (Weatherford et al. 2024):

1. Assessing TMS capabilities and performance.

2. Planning and developing strategic TMS plans, including agency strategic plans, TMSO and TMS programming and planning, and metropolitan planning organization TSMO and ITS planning.

3. TMS planning and feasibility studies, including planning and design of TSMO initiatives, operational strategies, and ITS projects.

4. TMS programming, administration, and resource allocation, including TSMO project selection and prioritization, TMS improvement projects, allocating resources for TMS maintenance and operations, and programming and planning.

5. TMS procurement and project development and implementation, including project design, development, and procurement.

6. TMS monitoring, evaluating, and reporting, including facilities performance monitoring and reporting, TMS asset monitoring and reporting, and TMS asset performance.

7. Ongoing maintenance and repairs of the TMS and TMS assets.

The TMS inventory information can be used to benefit any of the processes supporting TMS management. By incorporating inventory data into these processes, agencies can ensure more informed decisionmaking, better allocation of resources, more informed plan development, and improved system performance.

Inventory information can be leveraged in these processes in a few specific ways, as follows:

- Identifying trends and patterns in TMS asset performance, which can help prioritize investments and inform where resources are focused.
- Enhancing communication and coordination among stakeholders by providing a common understanding of assets, their condition, configurations, and performance.
- Informing plan development and the development of program performance measures, enabling agencies to track progress, set targets, and ensure effective TMS management and operations.
- Improving day-to-day management of TMS operations.

Agencies participating in the study offered information about the extent to which documented processes exist for incorporating the management of TMS assets into decisionmaking. The responses varied, with most agency representatives reporting no clear linkage. Only staff from Caltrans and Lake County Division of Transportation indicated a visible linkage, but neither mentioned specific processes.[57,58]

However, all agency representatives acknowledged the intrinsic value of the information and some emphasized the importance of progressing toward more comprehensive planning actions. Table 12 provides recommendations and lessons learned from these agencies in this regard.

[57]Interview with Caltrans staff member, 2021.
[58]Interview with Lake County, IL, Division of Transportation staff member, 2021.

Table 12. Agency lessons learned regarding using inventory information.

Agency	Recommendations	Lessons Learned
Caltrans[59]	• The agency should have started tracking inventory years ago. • Headquarters must provide clear direction to districts. • Staff must submit a standard subset of data.	• Need clear policy in a common clear format. • Need definition of data sets (e.g., what is working and not working). • Need policies to track things (e.g., construction and maintenance). • Need to obtain buy-in on activities.
Lake County, IL, Division of Transportation[60]	• Determining what data the agency will want to track years from now is challenging. • One commercially available solution may not fit all of an agency's needs. Agencies may need to procure a commercial product and modify it. Alternately, agencies may want to develop whatever solution they can in-house, as long as they are able to update and maintain the developed product as the need arises.	• Be prepared to evolve over time. Needs will be different 5 yr from now. • Technology is changing rapidly. The agency tracks eight different types of detection, all of which are managed differently. Maintaining all the detection types and their data is challenging. • The need to update data is the biggest lesson learned. Stale data are useless. • Only keep what data are needed. Too much data are available to keep them all. Only keep what data are necessary and important to reference later.

[59]Interview with Caltrans staff member, 2021.
[60]Interview with Lake County, IL, Division of Transportation staff member, 2021.

Agency	Recommendations	Lessons Learned
MDOT SHA[61]	• Plans to dedicate two positions specifically to ITS inventory activities. • Has staff dedicated to configuring assets, who does not currently plan and execute improved communication and alerts with devices and would need additional authority to do so. The existing two engineering staff are too busy to realistically manage all the urgent upgrades needed. These upgrades would happen faster if the agency had more staff authorized to make decisions.	• Technology maintenance needs strong leadership but often is not well understood across different organizational units, as its focus is slightly different in each case. • Procurement for contractual support for ITS needs to be managed by someone experienced with effective practices in ITS.
MARC[62]	• Only one city currently has a system to manage traffic signal assets. Other agencies tracked only some of their assets. Many issues should be tracked more. • MARC demonstrated the system to St. Louis, MO years ago and went forward with that business model. Some other cities have collaborated within their systems and worked together in similar situations.	N/A

[61]Interview with MDOT SHA staff, 2021.
[62]Interview with MARC staff member, 2021.

Agency	Recommendations	Lessons Learned
ODOT[63]	• Connect work processes involving changes to TMS assets (e.g., maintenance, repairs) with updating information in the inventory. • Focus on how an inventory can benefit users. • Do not just make inventorying extra work. • Develop clear procedures. • Include a QA procedure.	N/A

N/A = not applicable.

Note: These responses suggest that agency representatives interviewed for this study may not have full visibility into the planning-related results of their work. Alternately, given the relative newness of the process, the full implications of their efforts may be difficult to fully characterize. The currency of the agencies' activities provides sufficient indication that they intend to follow through with their efforts to support the planning and programming of TMS asset investments.

[63]Interview with ODOT staff member, 2021.

APPENDIX A. LITERATURE REVIEW

Table 13 lists the resources and references reviewed for this report.

Table 13. Resources and references.

Name	Source	Link
Handbook for Including Ancillary Assets in Transportation Asset Management Programs (report)	Allen et al. 2019	https://www.fhwa.dot.gov/publications/research/infrastructure/19068/index.cfm
"Transportation Asset Management Expert Task Group: Resources" (web page)	FHWA 2023	https://www.fhwa.dot.gov/asset/etg/index.cfm
A Strategic Framework To Support the Implementation of Transportation Asset Management in State Transportation Agencies (report)	FHWA n.d.	https://www.fhwa.dot.gov/asset/pubs/framework.pdf
"Integrating Asset Management Into the Transportation Planning Process" (presentation)	Mercer 2016	http://onlinepubs.trb.org/onlinepubs/conferences/2016/AssetMgt/76.LauraMester.pdf
Integrating Asset Management Plans Into Transportation Planning Process: A Briefing Paper (report)	AASHTO 2015	**Error! Hyperlink reference not valid.**https://www.tam-portal.com/wp-content/uploads/sites/12/2016/01/AM-Planning-Process.pdf
The Evolution of ITS in Transportation Asset Management (final report)	Weatherford and Schroeder 2020	http://enterprise.prog.org/Projects/2020/ENT-ITS-Asset-Mgmt-final-report.pdf
Configuration Management for Transportation Management Systems Handbook (final report)	Smith 2003	https://ops.fhwa.dot.gov/freewaymgmt/publications/cm/handbook/toc.htm
Elements of a Comprehensive Signals Asset Management System (final report)	Harrison et al. 2004	https://ops.fhwa.dot.gov/publications/fhwa_signal_system/

Name	Source	Link
Using an LCP (Lifecycle Planning) Process To Support Transportation Asset Management: A Handbook on Putting the Federal Guidance Into Practice (handbook)	Zimmerman et al. 2019	https://www.fhwa.dot.gov/asset/guidance/hif19006.pdf
"Information Technology Asset Management: It's All About Process" (article)	Provance® 2014	https://s0.whitepages.com.au/1682a770-80a7-4e17-b04c-85def4aa2158/gartner-australasia-pty-ltd-document.pdf
Traffic Management Capability Maturity Framework (fact sheet)	FHWA 2016a	https://ops.fhwa.dot.gov/publications/fhwahop16026/fhwahop16026.pdf
Traffic Signal Management Capability Maturity Framework (fact sheet)	FHWA 2016b	https://ops.fhwa.dot.gov/publications/fhwahop16028/fhwahop16028.pdf
"Automated Traffic Signal Performance Measures" (web page)	FHWA 2024a	https://ops.fhwa.dot.gov/arterial_mgmt/performance_measures.htm
"Completed Projects: TMC Performance Monitoring, Evaluation, and Reporting Handbook" (web page)	FHWA 2021	https://tmcpfs.ops.fhwa.dot.gov/projects/tmcpmerhdbk.htm
Transportation Asset Management Gap Analysis Tool	AASHTO 2014	https://www.tpm-portal.com/tool/tam-gap-analysis-tool-nchrp-08-90/
Asset/Fund Management Guidebook Technical Plan: ITS	Colorado DOT 2019	Not available
"Transportation Asset Management Plans" (web page)	FHWA 2024b	https://www.fhwa.dot.gov/asset/plans.cfm
"Asset Management: Questions and Answers (Qs and As)" (website)	FHWA 2019	https://www.fhwa.dot.gov/asset/guidance/faqs.cfm
Life-Cycle Assessment for Transportation Decision-Making (article)	Chester et al. 2014	https://www.transitwiki.org/TransitWiki/images/7/73/Life-cycle_assessment_fortransportation_decision-making.pdf
Major Equipment Life-Cycle Cost Analysis (final report)	Gransberg and O' Connor 2015	https://mdl.mndot.gov/items/201516

Name	Source	Link
A Life-Cycle Cost-Analysis Approach for Emerging Intelligent Transportation Systems With Connected and Autonomous Vehicles (report)	Gao et al. 2018	https://trid.trb.org/view/1496009
CalemEAM ITS Change Management Guide for the Virginia Department of Transportation (internal guidebook)	VDOT	Not available
Framework for Managing Data From Emerging Technologies To Support Decision-Making (report)	NCHRP 2020a	https://www.nap.edu/catalog/25965/framework-for-managing-data-from-emerging-transportation-technologies-to-support-decision-making
Guidebook for Managing Data From Emerging Technologies for Transportation	NCHRP 2020b	https://www.nap.edu/catalog/25844/guidebook-for-managing-data-from-emerging-technologies-for-transportation
Review of Traffic Management Systems—Current Practice	FHWA, July 2023	https://highways.dot.gov/research/publications/operations/FHWA-HRT-23-051
"ATMS Infrastructure Alignment Project" (web page)	NOCoE 2022	https://transportationops.org/case-studies/atms-infrastructure-alignment-project

APPENDIX B. LIST OF AGENCIES INTERVIEWED

Table 14 lists the agencies interviewed and the agency contacts.

Table 14. Agencies interviewed as part of this report.

State	Justification
TDOT	Recently presented on their integration of IT staff within DOT for improved operations and technology asset management.
MDOT SHA	Saw a presentation at an industry meeting regarding current efforts in asset management.
ODOT	Have ongoing effort in asset management.
Caltrans	Are procuring a new asset management system and deploying a new integrated software solution.
Lake County, IL, Division of Transportation	Manage a large number of assets.
MARC	Have ongoing effort in asset management.
VDOT	Have ongoing effort in asset management.

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The *Current Status of ITS Devices* dashboard depicted in figure 7 is taken from GDOT's internal ITS Asset Management System. The dashboard's *ITS Device Location and Asset Status Indicator* map utilizes mapping data from Mapbox® OpenStreetMap®.

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