Inventorying, Documenting, and Configuring Traffic Management System (TMS) Assets and Resources

December 2024

Publication No. FHWA-HRT-25-031

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
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Turner-Fairbank
Highway Research Center

FOREWORD

As State and local agencies look for ways to safely improve the mobility of the travelling public, they continue to design and implement traffic management systems (TMS) to help them achieve these goals. To help better manage these assets and resources, agencies have realized the importance of inventorying, documenting, and configuring these TMS assets. This technical report discusses the inventorying, documenting, and configuring of TMS assets and resources.

The report provides a framework for public agencies to navigate the range of issues and practices to support and systematically manage these assets throughout their lifecycle. It presents a range of issues pertinent to the selection, inventory, configuration, and documentation of assets and resources, facilitating their integration into the management, repair, and maintenance of TMS assets. Emphasizing the connection between the inventory, documentation, and configuration of TMS assets, the report aligns with practices that enhance the development, use, and maintenance of an asset inventory for the management and operation of TMSs. This report may be of interest to representatives from State departments of transportation, local agencies, metropolitan planning organizations, regional authorities, toll authorities, and other groups responsible for, supporting, or using a TMS asset and resource inventory.

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Recommended citation: Federal Highway Administration, *Inventorying, Documenting, and Configuring Traffic Management System (TMS) Assets and Resources* (Washington, DC: 2024) https://doi.org/10.21949/1521542

TECHNICAL REPORT DOCUMENTATION PAGE

<table>
<tr><td colspan="2">1. Report No.
FHWA-HRT-25-031</td><td>2. Government Accession No.</td><td colspan="2">3. Recipient’s Catalog No.</td></tr>
<tr><td colspan="3" rowspan="2">4. Title and Subtitle
Inventorying, Documenting, and Configuring Traffic Management System (TMS) Assets and Resources</td><td colspan="2">5. Report Date
December 2024</td></tr>
<tr><td colspan="2">6. Performing Organization Code:
HRSO-50</td></tr>
<tr><td colspan="3">7. Author(s)
John MacAdam, Paul Belella, Daniel Lukasik, Robert Sanchez
(ORCID: 0000-0002-0763-6146)</td><td colspan="2">8. Performing Organization Report No.</td></tr>
<tr><td colspan="3" rowspan="2">9. Performing Organization Name and Address
Leidos, Inc.
1750 Presidents Street
Reston, VA 20190

Parsons Corporation
2201 Dupont Drive,
Irvine, CA 92618</td><td colspan="2">10. Work Unit No. (TRAIS) HRSO-50</td></tr>
<tr><td colspan="2">11. Contract or Grant No.
693JJ322A000005</td></tr>
<tr><td colspan="3" rowspan="2">12. Sponsoring Agency Name and Address
Federal Highway Administration
Office of Safety and Operations Research and Development
6300 Georgetown Pike
McLean, VA 22101</td><td colspan="2">13. Type of Report and Period Covered
Report; August 2023–October 2024</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code HRSO-50</td></tr>
<tr><td colspan="5">15. Supplementary Notes
Task order manager: Jon Obenberger (HRSO-50; ORCID: 0000-0001-9307-847X)</td></tr>
<tr><td colspan="5">16. Abstract
This report assists public agencies in the inventorying, documenting, and configuring traffic management system (TMS) assets, and illustrates how such information can support the management of these assets. It provides information for agencies to establish and manage their TMS asset inventories. This document addresses key factors in determining which assets and resources to include in the inventory; the information to configure and document; and establishing, maintaining, and using controlled resources. It explores methods to integrate configuration management into the everyday maintenance and operation of TMS assets, as well as strategies for managing and facilitating access to the compiled data. Additionally, this report highlights the significance of documenting and configuring an inventory of TMS assets, and how this information has the potential to support other TMS activities, plans, and 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 involved in, supporting, or using a TMS asset and resource inventory.</td></tr>
<tr><td colspan="3">17. Key Words
Capabilities, Assessment, Performance, Reporting, Traffic management system, Traffic management center, asset management, intelligent transportation systems</td><td colspan="2">18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.
http://www.ntis.gov</td></tr>
<tr><td>19. Security Classif. (of this report)
Unclassified</td><td colspan="2">20. Security Classif. (of this page)
Unclassified</td><td>21. No. of Pages
93</td><td>22. Price
n/a</td></tr>
</table>

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

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

CC	configuration control
CCTV	closed-circuit television
CFR	Code of Federal Regulations
CI	configuration identification
CM	configuration management
CSA	configuration status accounting
DMS	dynamic message signs
DOT	department of transportation
DSRC	dedicated short-range communication
FHWA	Federal Highway Administration
HAWK	high-Intensity activated crosswalk beacon
IT	information technology
ITS	intelligent transportation systems
MaaS	mobility-as-a-service
MMU	malfunction management unit
MPO	metropolitan planning organization
PLC CPU	programmable logic controller central processing unit
RFID	radio frequency identification
RWIS	road weather information system
TAM	transportation asset management
TAMP	transportation asset management program
TMC	traffic management center
TMS	traffic management system
TSMO	transportation systems management and operations

CHAPTER 1. INTRODUCTION

As State and local agencies look for ways to safely improve the mobility of the traveling public, those agencies continue to design, implement, manage, operate, and maintain traffic management systems (TMSs) to achieve these goals. Agencies have expanded the deployment and enhanced the capabilities of TMSs to meet their performance objectives, which has resulted in increased investment and reliance on TMSs to manage traffic. Agencies have begun to recognize the benefit of inventorying TMS assets and supporting resources, and they see documenting and configuring as supportive measures to this end.

The purpose of this report is to present the practices, challenges, and issues to consider when inventorying, documenting, and configuring TMS assets and resources. The project team gleaned information for this report by reviewing available literature and interviews with agencies in several States.[1]

This report addresses issues for an agency to consider when determining which TMS assets and resources to inventory and what information to collect and maintain. The report also discusses how an agency can manage the inventory to allow others to access and use the information. The report also identifies opportunities for integrating information on TMS assets and resources with an agency or region's transportation systems management and operations (TSMO) program, processes, plans, or related activities. It covers the overall process and relationship of inventorying, documenting, configuring, and supporting the use of information on TMS assets and resources within a broader context of managing and operating TMSs.

The objectives of this report are as follows:

- Describe the value of establishing and managing an inventory of TMS assets and resources.
- Identify the issues agencies may consider when determining which TMS assets and resources to inventory and what information to collect and document.
- Emphasize the importance of documenting, configuring, and managing the use of information on TMS assets and resources.
- Illustrate how an inventory of TMS assets and resources may support other processes, plans, and activities conducted during the lifecycle of a TMS.

[1]Interviews with staff members of California Department of Transportation (DOT); Lake County, Illinois, Division of Transportation; Mid-America Regional Council; Maryland DOT State Highway Administration; Ohio DOT; Tennessee DOT; and Virginia DOT, 2021.

TMS ASSETS AND RESOURCES

A TMS is a complex blend of hardware, software, processes, and people performing a range of functions, services, and actions. TMSs contain assets that are relied upon to meet agencies' mission and performance objectives. These assets are physical and logical elements which can be managed to support the reliable operation of TMSs.[1]

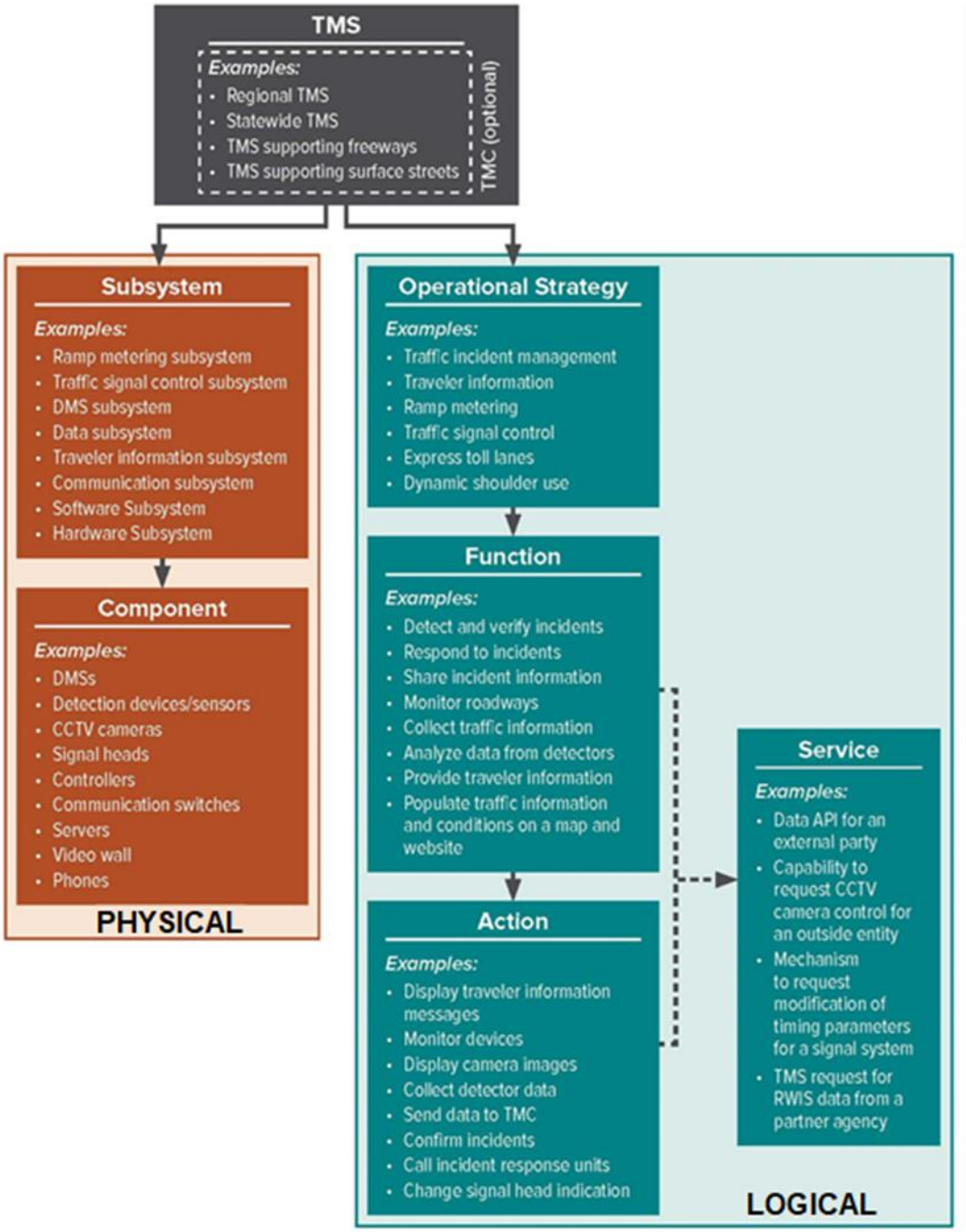
These assets may include hardware, software, infrastructure, or equipment, such as cabinets, foundations, or devices. A traffic management center (TMC) is often an important component of operating a TMS. The TMC is where the physical elements of the TMS connect to one another and to communications and computing capabilities. Therefore, a TMC is often a highlighted element in planning for a TMS. It is important that operation of the TMC supports the TMS vision, goals, and objectives.

The design or structure of a TMS can be broken down into physical and logical elements. The physical elements include the TMS subsystem and the components. The logical elements are the TMS operational strategies, functions, actions, and services. An agency's TMS is typically comprised of multiple subsystems (e.g., data, software, computing), each of which supports one or more of the agency's operational strategies.

Figure 1 depicts the general structure of a TMS. The figure shows the physical and logical elements, with examples of each, and the associated operational strategies. The examples in the figure are not comprehensive; an agency's TMS might not be comprised of all subsystems and components.[1] The solid and dashed lines in the figure depict the relationship in the structure for both the physical side and logical side of a TMS. The lines do not depict a flow of data or information. A TMS is not only comprised of the physical assets but also various resources, such as software tools, data sources, policies, procedures, and human resources. These resources support the operation and management of the TMS.

As transportation agencies expand the use of and investment in TMSs, agencies may benefit from consistently and effectively managing these assets. The purpose of monitoring device condition for periodic maintenance and eventual replacement is referred to as transportation asset management (TAM) for TMS. Managing TMS assets and resources may involve the activities, actions, and resources an agency may use to maintain and improve the assets' performance, condition, and lifespan. Benefits may include maintaining and improving performance, extending assets' lives, and more efficiently planning and budgeting for replacement of TMS assets once their recommended lifecycle has passed.[1]

After an agency establishes its need to manage TMS assets, a key activity is identifying which TMS assets to manage. This identification or classification process includes determining whether managing an asset is valuable and feasible and what improvements can be expected through managing the asset. This process supports understanding the data to collect and information to compile in support of monitoring or assessing the condition, performance, and needs of these assets. Inventorying is the practice of identifying, collecting, compiling, documenting, and managing TMS asset and resource information (e.g., location, installation date, age, and condition). The following section explores the methodologies and benefits of managing these assets.[1]



Source: Federal Highway Administration (FHWA).

Note: The solid lines show the internal system hierarchy and the dashed lines show the need for connection to external systems.

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

Figure 1. Diagram. TMS Structure.

MANAGING TMS ASSETS AND RESOURCES

Asset management is defined in 23 Code of Federal Regulations (CFR) § 515.5 as:[2]

> A strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis based upon 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 life cycle of the assets at minimum practicable cost.

Although asset management traditionally has been associated with highway infrastructure assets, such as bridges and pavement, managing TMS assets and resources require a distinctly different approach. TMS assets have unique lifecycles, depreciation rates, and characteristics—such as technology elements, monitoring capabilities, functional obsolescence, fungibility, portability, and communications—that are different than highway infrastructure assets. These characteristics make TMS assets distinct from traditional transportation infrastructure and may necessitate specialized management methods. For example, while a bridge may have a lifecycle of several decades, a TMS software component may require frequent updates and become functionally obsolete within a much shorter time frame.

The benefits of managing TMS assets could include efforts to support enhancing the availability, reliability, and dependability of the assets; managing data defining the assets; understanding maintenance needs; monitoring and measuring asset performance; and identifying resources and tools to support managing the assets. Managing TMS assets improves the reliability of assets over time by reducing maintenance, repair, and overall costs of managing and operating the TMS. This understanding also supports agency decisions involving the management, operation, or planning to support justifying improvements and optimize agency investments in their TMSs.

Managing TMS assets typically begins with establishing comprehensive situational awareness of an agency's assets, which leads to coordinated management of TMS assets over their lifecycles and enables incorporating this information across all functional entities and processes in the organization. The activities involved in managing TMS assets are described in *Managing Traffic Systems Assets*, which provides a framework for understanding how monitoring, performance, and real-time condition assessment support the functions, services, and actions of the TMS.[1] The following sections discuss activities agencies may consider in support of enhancing how they manage TMS assets and resources.

Identifying and Classifying TMS Assets

Asset identification and classification encompass steps an agency may consider when beginning an effort to establish an inventory of TMS assets and resources. Identification includes determining whether managing an asset is valuable and feasible, along with what improvements can be expected by managing the asset. This activity may consider all elements and resources that directly or indirectly support a TMS.

Classifying is intended to support an agency determining which TMS assets and resources may not be reasonable or feasible to manage. Classification also facilities grouping similar types of TMS assets or resources to determine what information to collect, monitor, and activities (e.g.,

maintenance, repair) to support each group. These groups may be based on common functions, criticality to operations, maintenance needs, or geographic proximity. Together, identifying and classifying TMS assets and resources establish what the agency finds beneficial to manage.

Inventorying TMS Assets

TMS asset inventory helps agencies understand and analyze asset condition and performance and effectively manage their assets. Inventory information may include attributes that describe assets or resources, such as an asset's make and model, age, classification, maintenance history, changes made to the asset, and performance or condition.

Managing and Maintaining TMS Asset Data

Managing TMS asset and resource data involve the collection, storage, and management of high-quality data. Agencies can capture data for TMS assets and resources through geographic information systems, maintenance management systems, specific data collection efforts, or when asset management activities are performed. Continual and systematic updating of this information is key, forming a detailed historical record that defines the current state and any changes in the status of TMS assets over time.

Providing access to a current inventory of TMS assets and resources serves not only as a tool for daily management and operational activities but also plays a role in strategic agency planning and decisionmaking. This inventory is kept relevant through regular updates on maintenance actions, parts replacements, repairs conducted, and proactive measures to prevent asset failures.

Centralizing access to these data streamlines its use, eliminates unnecessary duplication of effort, and ensures all stakeholders are informed from a singular, authoritative source. Agencies may consider augmenting their existing asset data management tools or adopting new solutions to meet their evolving needs.

Monitoring, Evaluating, and Reporting on the Condition of TMS Assets

Accurate assessment of TMS asset conditions enables an agency to establish the necessary activities for capturing, monitoring, and reporting on the performance expectations of its TMS assets. Information on the condition of various asset classifications is foundational for monitoring performance, informing decisions on maintenance, estimating remaining useful life, and evaluating maintenance costs and present value to the agency. Historically, challenges in assessing asset condition have stemmed from the lack of a comprehensive inventory and issues with collection, processing, and integration of condition information into other processes. For many agencies, the condition of an asset is directly related to its lifecycle stage, the resources required to maintain it, and lifecycle assessment strategies.

In this context, the processes of monitoring, evaluating, and reporting of TMS assets are key. Asset monitoring tracks the condition and operational status of assets. Asset evaluation analyzes these data to understand an asset's condition, projected performance, and value. Asset reporting disseminates TMS asset information, which can inform different functions, actions, or processes throughout the asset's lifecycle.

Managing TMS asset data incorporates data governance to assure the timeliness and quality of this asset information. Systematic updates and data governance practices enable an agency to make well-informed decisions for asset maintenance and operation. Consequently, these processes, procedures, and abilities to monitor, capture, and preserve information on asset conditions become instrumental in the management of TMS assets.

Managing TMS Asset Spares

TMS assets may consist of swappable or spare components, devices, or parts. Such replacements may occur during maintenance or to restore functionality to nonoperational assets, as well as to maintain optimal asset performance. Given the interchangeable nature of TMS assets, maintaining a stock of spares is key. Including these spares in the TMS asset inventory enables effective forecasting of future activities such as maintenance, repairs or replacements. This practice also facilitates ongoing monitoring of asset condition, ensuring compliance with performance standards and targets.

Configuring TMS Assets

Managing an inventory of TMS assets and resources is a dynamic process that involves detailed tracking of information for each managed asset classification. The practice of maintaining, repairing, or replacing assets necessitates updating the TMS asset inventory to reflect these changes. Configuration management (CM) is a practice that supports agencies in systematically documenting, tracking, and verifying changes to ensure the integrity of the asset inventory and supporting documentation.

The TMS asset inventory, enhanced by CM, becomes a comprehensive record that serves as a backbone of a robust TMS. It captures extensive details that are foundational for effective decisionmaking, asset utilization, and long-term planning. For agencies without an existing TMS asset inventory, understanding CM's role is key. An agency can take key steps to create and inventory and can also leverage CM for its ongoing utility.

DEVELOPING AND MANAGING AN INVENTORY OF TMS ASSETS

An inventory of TMS assets and resources is a collection of information. The inventory is dynamic and comprehensive, designed to support the complete lifecycle of an asset, as well as the management and operation of the TMS. The specific information included in a TMS asset inventory may vary from one agency to another, reflecting the unique needs and priorities of each organization.

Chapter 3 presents information supporting the consideration of several approaches to using classifications of TMS assets to support determining what information to include in an inventory. It also introduces the potential range of assets and resources to consider for an inventory, emphasizing the collection of information which is both useful and obtainable. This highlights the desire to balance the level of effort with the expected value. Assets typically incorporated into a TMS inventory may include a wide range of components and devices, such as closed-circuit television (CCTV) cameras, changeable message signs, and vehicle detection devices. Additionally, resources that agencies may consider including in an inventory could include designs, specifications, plans, warranty documents, licenses, and agreements.

Chapter 4 explores the motivation for inventorying assets, provides examples of making value based decisions on what data to collect and save. It also explains the process and issues to consider in support of developing, managing and maintaining an inventory. The purpose of an inventory extends beyond tracking and saving information, to supporting how access to information on the condition of assets and the inventory supports the efficient management and operation of a TMS.

Data attributes included in the TMS asset inventory align with the types of assets and resources being inventoried. Some agencies may have existing data captured for certain assets. Additional attributes may need identification for a comprehensive inventory.

Chapter 4 provides more details on the practices and activities that support agencies in developing and managing a TMS asset inventory, including:

- Determining the appropriate inventory information for managing TMS assets.
- Establishing an inventory based on existing asset classifications.
- Considering the tools used to monitor the condition of assets.
- Understanding existing processes that can easily be used to maintain an inventory.

DOCUMENTING TMS ASSETS

Documenting TMS assets involves capturing and saving information about TMS assets and resources. The objective is to capture information on a device's or classification of an assets' history, current condition, specifications, product manual, design, installation records, testing, warranty information, and acceptance. Documentation can support using this information to bring to light patterns of device performance, maintenance history, and details an agency can use when managing, operating, using, and maintaining each TMS asset classification or specific type of asset and its supporting resources.

The documentation supporting each TMS asset and support resource can also be used in management activities throughout the TMS lifecycle. These activities may include planning for maintenance, replacement, and identifying acquisition needs that may be incorporated into the funding for the TMS program or agency's overall TSMO program.

Documenting can also involve developing and publishing materials to comply with agency reporting requirements. These materials support decisionmaking, which is helpful for obtaining the necessary resources. These resources include funding, staffing, and training for maintaining, or upgrading assets. Chapter 5 explores documenting TMS assets to support an inventory by examining the methods, quality control processes, and integration strategies for long-term inventory maintenance.

CONFIGURING TMS ASSETS

Configuring TMS assets is the process of optimizing their technical setup to achieve peak performance and ensuring the TMS operates as designed and expected. CM applies processes and procedures to control system changes. TMSs are in states of constant change due to the continued modifications in various subsystems, components, and devices.

Device modifications often occur during maintenance, repair, or upgrade efforts. The installation of new devices may involve software or other technologies that differ from those in existing devices, which are already included in the inventory, and have documentation maintained. CM starts with documenting changes to a system to capture and maintain its current configuration within the inventory. Then, the CM process ensures this configuration is preserved whenever changes take place, creating a clearer understanding of what information to compile, save, and how this information relates to and builds upon what is already documented and included in a TMS's inventory.

MANAGING A TMS ASSET INVENTORY

Asset management, as defined in 23 CFR 515.9(d)(1), refers to the objectives aligned with an agency's mission to achieve and sustain a desired state of good repair over the lifecycle of its assets at a minimum practicable cost.[(2)] Managing assets focuses more on the ongoing reliability and performance of each individual asset.

Managing TMS assets is a specialized process that differs from general asset management. It involves optimizing the performance of TMS assets to support the TMS operating at its intended level and adapting to continual changes in the system. Similar to most processes, managing a TMS asset inventory adds a demand on agency resources. This process concentrates on the dynamic nature of TMS assets, their unique requirements, and the importance of monitoring asset conditions and maintaining this information in the asset inventory.

Before developing a TMS asset inventory, agencies would benefit from identifying the specific TMS assets they need to manage. TMS assets may include various field devices, communications equipment, software applications, and other components that enable TMS operations.

Once the TMS assets are identified, agencies can determine the relevant data elements and information to be included in the inventory. The selection of data elements would align with the agency's TMS, TSMO, or other strategic goals or objectives related to managing these assets effectively.

The process of maintaining a TMS asset inventory involves several considerations:

- Developing the inventory by capturing and organizing the relevant asset data and information.
- Maintaining the inventory by routinely updating the data and documentation to reflect changes in the TMS assets and their configurations.

- Applying CM practices to ensure the inventory represents the current state of the system and asset configurations.

- Assigning staff responsible for managing the inventory tasks, considering their capacity and familiarity with the TMS assets.

Agencies may need to identify and allocate resources to support the development, maintenance, and use of the TMS asset inventory. This may include personnel, tools, and processes specifically tailored for inventorying TMS assets.

The selection of tools for creating and maintaining the inventory may be influenced by how they integrate with the agency's existing tools and processes. Common options include spreadsheets or commercial off-the-shelf products designed for asset inventory and maintenance management. These tools can enhance the efficiency of managing the TMS asset inventory and reduce the demand on staff time, provided they integrate well with the agency's existing tools and processes.

Using the TMS asset inventory data can support various activities, such as lifecycle management, planning, and informed decisionmaking regarding investments and resource allocations for TMS assets. Agency staff who use the TMS asset inventory data would benefit from understanding the scope of the collected data and the processes in place for managing this information.

INTENDED AUDIENCE

This document is targeted to practitioners who manage TMS assets and rely on the assets to perform at expected levels. Practitioners may include managers and supervisors, transportation engineers and planners, maintenance personnel, the research community, and others who have a role with TMSs or an agency's TSMO program. The intended audience includes State departments of transportation (DOTs), local agencies, metropolitan planning organizations (MPO), regional authorities, toll authorities, and other groups involved in or that support TMSs. Consultants, contractors, and researchers who work with TMSs, or support agencies that operate TMSs, may also benefit from this report.

DOCUMENT ORGANIZATION

This report has nine chapters and is organized as follows:

- Chapter 1: Introduction. This chapter introduces the report, its purpose, defines the concepts of a TMS inventory, managing TMS assets, and documenting and configuring TMS assets in support of an inventory.

- Chapter 2: Inventorying, Documenting, and Configuring TMS Assets and Resources. This chapter provides an overview of inventorying, documenting, and configuring TMS assets and context of how these activities may be incorporated into other processes within the lifecycle of a TMS or the supporting program.

- Chapter 3: Preparing to Develop a TMS Inventory. This chapter provides the range of issues an agency might consider before initiating an effort to develop an inventory of TMS assets, including motivations and effective practices.

- Chapter 4: Inventorying TMS Assets and Resources. This chapter discusses the specifics of inventorying TMS assets and resources. It explores motivations for creating an inventory, considerations for inventory management, relevant data attributes and quality control measures, and procedures for handling inventory data.

- Chapter 5: Documenting TMS Assets and Resources. This chapter discusses the benefits of proper documentation and use of this information to support the entire lifecycle management of all TMS assets.

- Chapter 6: Configuring TMS Assets. This chapter focuses on configuring TMS assets and explains the connection between inventory management of TMS assets and resources and CM procedures and practices. It provides practical steps and considerations for integrating TMS inventory information into an established CM process to ensure the inventory remains up to date and maintains its integrity during system changes.

- Chapter 7: Incorporating Inventory Practices into Managing and Operating a TMS. This chapter shares potential benefits of leveraging information captured in an inventory of TMS assets into other processes and activities which occur throughout the lifecycle of a TMS.

- Chapter 8: Incorporating the TMS Inventorying into Agency Planning Efforts. This chapter explores the benefits of incorporating information captured in an inventory of TMS assets into agency planning efforts and other existing processes.

- Chapter 9: Maintaining Inventory, Configuration, and Documentation Quality. The final chapter provides information and examples of practices agencies have used to integrate daily maintenance, repair, and other activities to maintain the inventory of TMS assets and resources.

- Appendix. Literature Review.

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

The purpose of this chapter is to provide an overview of inventorying, documenting, and configuring TMS assets and resources within the context of an agency's broader management and operation of a TMS, its supporting program, and the agency's TSMO program. It outlines how these activities directly apply to various processes that support improving the management, operation, and performance of a TMS.

Key issues addressed in this chapter include:

- The value of a TMS inventory in agency processes.
- Core principles of managing TMS assets.
- Considerations for initiating, developing, and maintaining a TMS inventory.
- Documenting TMS assets to support asset management.
- Recommendations for configuring a TMS inventory.
- Benefits of inventorying, documenting, and configuring TMS assets.

By understanding these key concepts and their interrelationships, agencies can better integrate TMS asset inventory information into the different TMS lifecycle processes and planning activities. Additionally, TMS asset information can be leveraged to support the planning and programming activities of an agency's or region's TSMO program, plans, and policies.

Figure 2 how various agency TMS processes and plans may be integrated, highlighting the role of a well-managed TMS inventory that relies on monitoring, evaluating, and reporting processes. This inventory information may support a range of different planning processes, plans, and processes involving decisionmaking about assessing and managing TMS assets.

The sections in this chapter are as follows:

- The Value of a TMS Inventory.
- Managing TMS Assets.
- Initiating a TMS Inventory.
- Documenting TMS Assets.
- Configuring a TMS Inventory.
- Benefits of Inventorying, Documenting, and Configuring TMS Assets.

This chapter includes the following sections:

- The Value of a TMS Inventory. This section provides an overview of how a TMS inventory can be used to inform planning activities, strategic plans, and other processes that support the active management and operation of a TMS.

- Managing TMS Assets. This section provides the activities to consider in support of managing TMS assets.

- Initiating a TMS Inventory. This section provides key considerations for determining what to include in a TMS asset inventory.

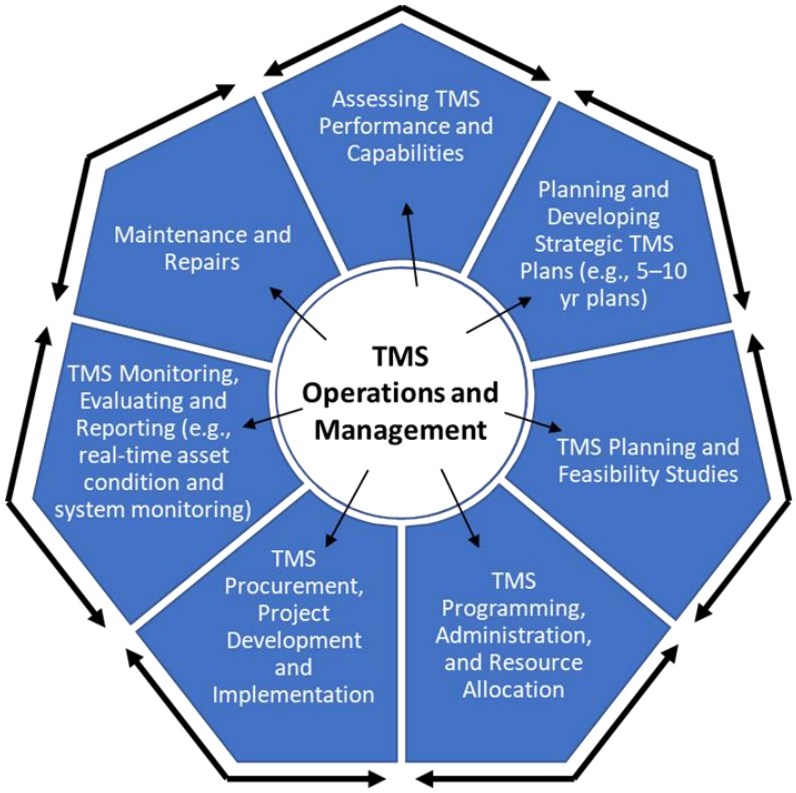
- Documenting TMS Assets. This section provides key objectives and considerations when documenting TMS assets.

- Configuring a TMS Inventory. This section provides an overview of CM processes and procedures and other considerations when documenting TMS assets.

- Benefits of Inventorying, Documenting, and Configuring TMS Assets. This section describes the benefits of leveraging the inventory information for making well-informed decisions to enhance TMS operations and performance.

THE VALUE OF A TMS INVENTORY

A comprehensive and well-managed TMS inventory is a foundational element that supports various agency processes and plans related to the management and operation of a TMS. Figure 2 illustrates the interconnected nature of these processes and plans, highlighting the central role of the TMS inventory. A key output of a TMS asset inventory is the current data it provides and compiles regarding TMS monitoring, evaluating, and reporting processes. An inventory of these assets and resources offers the potential to yield information about the agency's TMS assets, including status, condition, performance, and needs. This data can be used to inform planning activities, strategic plans, and other processes which support the active management and operation of a TMS.



Source: FHWA.

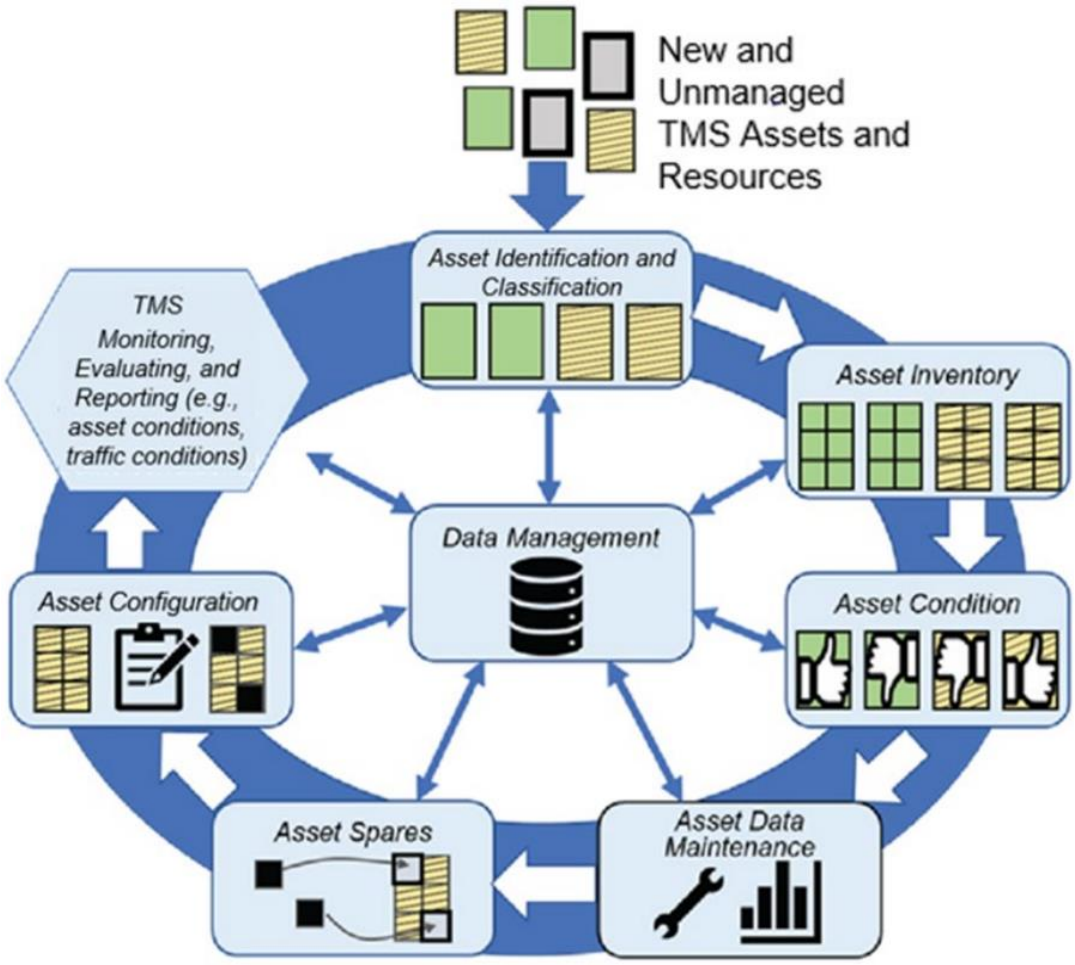
Figure 2. Illustration. Agency processes and plans for traffic management systems.

For example, a planning process considering possible TMS improvements may rely on inventory data to identify gaps in the current system, while the maintenance and repairs phase may use cost and condition information from the inventory to make decisions about asset replacement. The TMS inventory also supports the development of strategic TMS plans and other agency studies by providing information on the current condition of the system.

The information in a TMS asset inventory is not static. It is continually updated through monitoring, evaluating, and reporting processes to reflect changes in asset condition, performance and configuration. This up-to-date information is helpful for making informed decisions about assessing, managing, and operating TMS assets. The information also feeds into various TMS planning activities, plans, and other processes throughout the lifecycle of the TMS.

MANAGING TMS ASSETS

Figure 3 illustrates the activities to consider in support of managing TMS assets. These activities include identifying, classifying, assessing, configuring, managing, and maintaining assets; evaluating asset conditions; managing asset data; and maintaining asset spares inventory. All of these activities contribute to effective TMS monitoring, evaluating, and reporting.



Source: FHWA.

Figure 3. Diagram. Managing traffic management system assets activities.

Asset management is defined in 23 CFR § 515.5 as a strategic and systematic process for operating, maintaining, and improving physical assets.[2] While this definition applies to traditional infrastructure assets like bridges and pavements, managing TMS assets demands a distinct approach due to their unique lifecycles, technologies utilized, depreciation rates, and characteristics.

The *Managing Traffic Management Systems Assets* report highlights these differences, noting that TMS assets require specialized management methods that prioritize availability, reliability, and dependability.[1] Effective management of TMS assets involves a holistic approach that incorporates:

- Identifying and inventorying assets.
- Deciding what to document and how it may be stored and used.
- Managing, documenting, and configuring changes to assets.
- Maintaining asset data and integrating them into other agency processes throughout the asset's lifecycle.

Developing, maintaining, and using information in a TMS asset inventory allows an agency to support the management of these assets. This information can also support the consideration of TMS assets in the agency's broader asset management efforts.

An inventory of TMS assets helps agencies manage and maintain these assets effectively. Inventory information not only supports managing assets but also enables day-to-day operation of a TMS. It facilitates routine preventative maintenance, optimizes asset condition and performance, and ensures any TMS functions and services that rely on specific assets can be delivered reliably.

INITIATING A TMS INVENTORY

Before creating an inventory of TMS assets, agencies may consider if an inventory already exists or if some level of inventory or related information exists that could be expanded upon. In some cases, an update to and enhancement of an inventory may be enough. If an inventory does not already exist, or if an existing inventory requires significant expansion, then starting a new effort to develop an inventory might be the next step for agencies.

Obtaining resources to support an effort to update an existing inventory or initiate the establishment of a new inventory is a key consideration. Agencies may need to justify the need for allocating resources towards this effort. When an agency initiates an effort to establish inventory for TMS assets, the scope of what might be included in the effort may vary based on the size and complexity of their system, how the inventory and supporting information may be used, and resources available to develop and maintain this information. What an agency decides to include in a TMS asset inventory will depend on their unique needs and objectives.

Key considerations for determining what to include in a TMS asset inventory may include:

- How asset condition information is used to manage and operate the TMS.
- How asset condition information may be accessed and used by various stakeholders.
- How asset condition data can support maintenance and repair activities.

Agencies may also consider how the inventory aligns with and supports their broader organizational goals and plans such as transportation asset management program (TAMP), TMS plans, or TMSO plans. As an example, agencies might consider monitoring the conditions of their vehicle detectors. This information could serve dual purposes: 1) identifying units that may need maintenance or 2) understanding how the performance of these units may be affecting the reliability of travel times estimates. If a significant number of detectors are malfunctioning, the accuracy of the generated travel time estimates could be compromised.

When deciding which information to capture in an inventory, agencies may consider an asset's utility in meeting both the TMS and the organizational goals. This may involve understanding who would gather the data, how the data would be used, and where the data would be stored and accessed. It would be beneficial if agencies chose tools for capturing and storing the information that align with organizational objectives.

Agencies may also consider data retention policies and how to ensure data quality and assign maintenance responsibilities. Before initiating an inventory, agencies might want to consider how to avoid introducing burdensome processes or changes. Efforts that are too cumbersome may face internal resistance, which reduces the inventory's value. Therefore, balancing comprehensiveness and operational practicality is key.

DOCUMENTING TMS ASSETS

Documenting TMS assets involves creating and maintaining records of asset information to support the agency in managing these assets throughout its lifecycle. The scope and nature of this documentation may vary based on the agency's asset classification and management approach. Key objectives of documenting TMS assets include:

- Supporting asset management and decisionmaking throughout the asset's lifecycle.
- Aligning documentation with the agency's asset classification structure.
- Ensuring documentation is comprehensive, up-to-date, and accessible to relevant stakeholders.

When determining what information to document, agencies can consider several factors related to the asset's performance, maintenance requirements, and contractual obligations. Initially, an agency could evaluate the measurability and trackability of the device's performance over its lifecycle. Agencies could also examine the existence and efficacy of maintenance processes and the asset's need for regular preventative maintenance.

Other considerations may include warranty terms for validation as well as warranty durations. Additionally, agencies can evaluate the sufficiency of information they collect during maintenance activities for updating inventory and configuration details. Maintenance work orders can likely refer to vendor-provided or approved procedures. Keeping these resources current as hardware or software configurations evolve is key.

Agencies may also consider aligning their documentation practices with their reporting requirements, as this can impact how resources such as funding, staffing, and training are secured. Documentation related to maintenance activities, asset performance measures, and service level agreement compliance may influence agency performance reports. To support this, agencies can consider providing structured tools for accessing a variety of data types and formats, such as business intelligence dashboards with detailed analytics.

CONFIGURING A TMS INVENTORY

CM is a series of processes and procedures for managing, maintaining, and updating an inventory of TMS assets. CM was developed in the information technology community to establish and maintain system integrity. Two fundamental purposes of CM are to establish system integrity and maintain system integrity. CM adopts a comprehensive approach for systematic evaluation, implementation, and verification of changes specific to TMS assets included in the inventory.

A system with integrity, as managed through CM, is one that is well-defined, documented, and available for providing TMS functions and services. This integrity allows the system to be readily integrated with other regional intelligent transportation systems (ITS) and ensures a high degree of traceability, facilitating easy identification of how system functions are technically provided.

The CM process typically includes the following steps:[3]

- Configuration identification (CI): Identifying and documenting the functional and physical characteristics of an asset's configuration.
- Configuration control (CC): Controlling changes to CI's and its related documentation.
- Configuration status accounting (CSA): Recording and reporting on the status of proposed changes and the implementation status of any approved changes.
- Configuration audits: Verifying that the actual configuration of a CI matches the documented configuration.

An agency may consider the following steps when using CM to support a TMS inventory:

- Evaluate the anticipated impact of proposed configuration changes to TMS assets within the inventory.
- Verify that executed changes are reflected accurately in the TMS inventory.
- Keep the inventory updated with current configurations and associated documentation.
- Link maintenance actions directly to the specific configurations of TMS assets in the inventory.
- Maintain an archive within the inventory for historical configuration changes, facilitating possible rollbacks.
- Provide instructions to maintenance staff for validating configuration changes within the TMS inventory.
- Use the updated inventory data to make informed decisions about whether to upgrade or replace specific TMS assets.

An important function of CM is keeping the TMS asset inventory accurate and up-to-date. This function ensures that agency staff can access a reliable source of current configuration details and history. This information is important for risk assessment, optimal scheduling of activities, and effective communication with vendors.

BENEFITS OF INVENTORYING, DOCUMENTING, AND CONFIGURING TMS ASSETS

Once an agency has created or updated a TMS asset inventory, it can leverage the inventory information for many benefits. The inventory data provide agencies with information to draw key insights for making well-informed decisions to enhance TMS operations and performance. Additionally, the insights support effectiveness and longevity of individual TMS assets. Agencies can also use inventory information to proactively manage asset lifecycle maintenance and support appropriate application of resources. The inventory information can also support long-term planning, such as TMS enhancement plans or other strategic plans impacting TMS operations.

Agencies may find the processes of inventorying, documenting, and configuring TMS assets to be interconnected, each reinforcing the other to maintain the integrity and utility of the TMS inventory data. For example, when incorporating new TMS devices into an inventory, the detailed documentation of their specifications and careful CM keeps the inventory data relevant and actionable.

An inventory of assets and resources that are part of a TMS is foundational for agencies to manage and operate their TMSs. Inventorying assets allows for this information to be accessed and used in support of informing maintenance schedules, benefiting operational strategies, aiding in real-time TMS functions, and benefiting long-term TMS planning processes. As an example, this information can be used to develop a preventative maintenance schedule for the assets. A TMS inventory may contain information on the condition of TMS assets. Whether the preventative maintenance occurs in-house or through a contract, the quantity of devices and their current condition are factors in determining the level of effort for maintenance tasks. Asset condition information can be beneficial to many tasks involved in managing and operating a TMS.

Documenting asset information (e.g., number of device failures per time period or number of maintenance work orders per particular asset type) provides agencies situational awareness about potential issues with condition, performance, or quality of different assets or classifications of assets. This documentation can be key for maintaining system integrity and optimizing the asset performance across the entire system. CM practices ensure the documented information reflects the current state and configuration of TMS assets.

CM encompasses hardware adjustments, software updates, and field device modifications. This information provides a historical record of changes. Agencies can leverage this information when planning routine upgrades, asset replacement projects, or future system enhancements. A more complete historical picture benefits and informs the agency’s plans for future improvements more holistically.

Inventory and asset condition data serve as key inputs for several agency processes, including planning and developing specific TMS, ITS, or TSMO projects. These data can also highlight when assets might require replacement or maintenance, helping agencies prioritize procurements and improve activities with a strategic approach.

CHAPTER 3. PREPARING TO DEVELOP A TMS INVENTORY

Developing or updating a TMS asset inventory can present challenges for agencies, such as incomplete or outdated inventories, overly expansive tracking of assets, or lack of actionable information in existing inventories. These issues can hinder an agency's ability to manage TMS assets and accomplish broader traffic management or agency TSMO program objectives.

The purpose of the information presented is to help agencies address these gaps and improve the comprehensiveness and utility of their TMS asset inventories, or to initiate an inventory if one does not already exist.

The objectives are to provide information on:

- Classifying TMS assets to include in an inventory.
- Determining what information to include in a TMS asset inventory.
- Using inventory information and resources effectively.
- Establishing or updating an inventory.

This chapter covers the process, steps, potential information sources, and examples of tools that may facilitate an agency creating or updating an inventory of TMS assets and resources. The chapter also discusses potential stakeholders, resources, and issues to consider within these processes.

The issues addressed include:

- Identifying and classifying TMS assets for inclusion in an inventory.
- Determining the appropriate level of detail for inventory information.
- Leveraging existing resources and data sources.
- Planning and executing the inventory process.

The following sections cover these topics and issues:

- Identifying TMS Assets and Resources. This section covers methods and techniques for determining what assets and related information to include in an inventory.

- Classifying TMS Assets. This section refers to the process of categorizing assets based on common attributes and the benefits associated with this approach.

- Using TMS Inventory and TMS Resources. This section provides information about several types of resources related to TMSs that agencies may consider including in an inventory.

- Planning to Inventory TMS Assets and Resources. This section provides a list of factors for an agency to consider during the initial stages of creating an inventory.

IDENTIFYING TMS ASSETS AND RESOURCES

After establishing the need for a TMS inventory and defining objectives, agencies may identify and classify TMS assets, which often fall into the following three groups:

- Assets requiring management to enhance or maintain functionality, operation, and life span.
- Assets requiring operation for system reliability and performance.
- Assets for which information will be collected and included in an inventory.

The identification process includes determining whether inventorying an asset is valuable and feasible and what improvements can be expected through inventorying the asset. Classifying similar types of assets provides clarity and understanding about the information an asset may decide is reasonable and feasible to collect, save, and use. During the classification phase, agencies may group assets in a number of ways, including:

- Similar evaluation processes.
- Related data to be collected for the inventory.
- Similar maintenance needs.
- Similar importance to the active management and operation of the TMS.

The result for each agency for this classification process is a structure that supports understanding the condition, performance, and needs of the TMS assets to be managed and included in an inventory. Assets typically refer to physical or tangible items with economic value that an agency owns or controls. Resources refer not only to tangible assets but also capabilities or skills that can be leveraged to achieve agency goals.

The key to understanding the identified and classified assets is to define them with inventory information. This information may include data points such as an asset's make and model, installation, and classification. It could also include configuration information such as maintenance history, changes made to the asset, and information about the asset's performance or condition. This information helps an agency understand and analyze condition and performance as they manage the asset TMS.

When considering feasibility of including both assets and resources in an inventory, agencies may consider the following questions:

- Is the information for the TMS asset or resource readily available?
- What is the level of effort required to gather and maintain the information?
- Does the effort align with the value of the information for managing the assets or the resource?

- Is this information likely to change over time, and what processes can be put in place for future updates?
- Does the asset or resource align with the agency's TMS objectives and priorities?
- How can the information be used to support other agency efforts such as TSMO program goals?
- Are there legal or contractual constraints on tracking the asset or resource?
- What are the implications, if any, of excluding the asset or resource in the inventory?

The answers to these questions will vary by agency. A key consideration when identifying potential assets and resources to include in an inventory is which assets may benefit from being managed. Managing TMS assets can improve or maintain the assets' functionality but takes agency resources. Agencies may decide to prioritize managing newer devices over older assets near their end of life. For example, a lane use control sign deployed over a lane on a freeway may take priority over an outdated highway advisory radio that is not being maintained, repaired, or replaced.

Funding constraints may limit the amount of TMS assets and resources an agency is able to include in an inventory. The importance of each asset to the TMS and the value of the inventory information for managing and operating the system may be considered when deciding what to include. The cost of collecting and maintaining the inventory data could be weighed against the potential benefits of having that information available for use.

Utah DOT mentioned determining what to inventory and what not to inventory as a challenge when identifying assets.(4) Their approach has been to balance the desire to manage assets with recognizing the limited resources. In addition to which resources it manages, Utah DOT also considers which detailed asset information is worth tracking, which is shown in table 1. Utah DOT identified the assets in table 1 with an understanding of what is of value and what can effectively be inventoried. Utah DOT identifies what TMS assets correlate to the asset subsystem and component levels.

Table 1. Asset hierarchy for identifying assets for inventory in Utah.[4]

Asset Category	Asset Components
Cabinet	Box, cabinet- traffic management system (TMS), cabinet-signal
CCTV	Camera, camera cable, Camera-live view, Camera-road weather information system (RWIS), encoder, remote data port
Communication	Communication hub, dedicated short range communications (DSRC), media converter, modem, radio, switch
Data Collection	Wireless data collector, continuous count station, controller, detection, detection interface, traffic management station
Electronic Sign	Animal crossing warning, truck prohibited sign
Express Lanes/Tolling	Antenna, detection, remote relay reboot device, radio frequency identification (RFID) reader, single-board controller, transponder signal indicator, variable toll message sign, programmable logic controller central processing unit (PLC CPU)
Freeway Lighting	Freeway lighting
Power Distribution	Battery, inverter, meter base, solar charge controller, uninterruptible power supply
Ramp Meter	Controller, detection, road surface sensor, RWIS tower
Signal	Audible port controller, controller, detection, detection interface, malfunction management unit (MMU), school crossing guard key switch
Signal Testing	Flasher, high-intensity activated crosswalk beacon (HAWK), signal
Variable Message Sign	Controller, portable sign, sign
Variable Speed Limit	Controller, sign structure

When identifying TMS assets and resources to include in an inventory, an agency may consider distinct levels of assets to include. Identifying the appropriate level of assets to classify and include in an inventory may help an agency understand what data and information are appropriate to collect and maintain. This choice depends on what the agency finds most useful and manageable for collecting and maintaining inventory data. Potential levels include:

- The entire TMS.
- Specific TMS subsystems (e.g., traffic signal systems).
- TMS components.
- Individual devices within a component.

For example, an agency might focus on a traffic signal system, which can contain various devices such as traffic signals, detection devices, or pedestrian signals. Each device may have its own components or subcomponents, such as lenses, controllers, or individual sensors. The rationale for focusing on each level can vary according to the following:

- System: Asset information at this level supports high-level reporting for planning, and performance purposes and providing information to decision makers.

- TMS subsystem: Information at this level supports assessing the capabilities, performance, and operational impact of TMS assets, as well as reporting on the performance and impact of these assets for operations activities.

- TMS component: Information at this level is practical for management, operation, maintenance, and performance monitoring and reporting, including pinpointing the causes of failures or performance variance.

- Individual TMS devices or elements: Information at this level includes the discrete elements that make up a component. Tracking these elements in an inventory is useful for managing asset configuration and maintenance, especially when individual devices can be swapped out or replaced.

CLASSIFYING TMS ASSETS

The goal of classifying TMS assets is to create an inventory structure that delineates asset types for better tracking, reporting, and future analysis. This ties back to the activities shown in figure 2 for managing TMS assets. Classifying assets helps agencies identify the specific data and information to collect and include in the inventory, based on the available resources and intended use of the information. Effective classification allows agencies to compare assets within their classes, aggregate asset information by class, coordinate maintenance needs and their prioritization by class, and evaluate maintenance, costs, and performance by class.

Specific objectives of asset classification include:

- Comparing similar assets within the inventory.
- Aggregating information to identify overarching needs by asset class.
- Prioritizing maintenance needs based on asset classes.

Assets may be categorized into different levels, such as:

- Hardware or software elements.
- Types, such as servers or cameras.
- Location, such as field devices or on-site assets.

Asset categories refer to broad groups, such as hardware or software. Classes within these categories are more specific, such as servers under the hardware group or traffic control software under the software group. Differentiating between categories and classes can help granulate the inventory for precise management. When classifying assets, agencies may consider classifying them according to attributes such as operational significance, maintenance requirements, or assessment of how each asset will be managed. When focusing on classification, agencies can build an effective TMS asset inventory that supports managing or maintaining the asset and also aids in reporting and decisionmaking. Inventory-focused classification allows agencies to answer questions about which assets they have, where assets are located, and what condition they are in.

Additional considerations for classification include:

- Risks of adverse impacts to travelers and/or the agency: Assets can be classified based on their impact on traveler safety and agency operations. For example, assets such as data subsystems, communication subsystems, and software subsystems may be classified as a higher-tier category. Conversely, assets may be classified as lower priority if they are less impactful to TMSs functions, actions, or services which may impact traveler safety or agency operations, provide fewer benefits to travelers and the agency, or are located in remote or less-traveled areas.

- Performance targets for each tier or class of assets: Assets can be classified based on targeted availability and performance measures, and the need to monitor and maintain this asset class to achieve them. The highest tier would likely include assets most important for system operations that need to be available for system functionality.

- Condition level of the assets: Assets can be classified based on their condition, in order to determine priority for replacement or repair. The condition can serve as a key factor for maintenance and investment decisions within the TMS inventory.

- Maintenance needs of the assets: Assets can be classified based on the types and levels of maintenance they need. Understanding trade-offs and benefits of maintenance efforts can shorten the decisionmaking process.

Table 2 provides an example of ITS assets classified into three tiers, based on relative importance of the asset to operations, maintenance considerations, and performance expectations. Classification of assets to the tiers in this example are based on the following definitions:

- Tier 1

    - Asset is necessary for system operations.
    - Minimal downtime is allowed.
    - Measurement targets are identified and tracked in realtime.
    - Dedicated prioritized funding received.

- Tier 2
    - Asset is highly beneficial to system operations.
    - Device is repaired within reasonable time frames.
    - Measurement targets are identified and tracked
- Tier 3
    - Asset is beneficial but not detrimental to system operations.
    - Item repaired or replaced when damaged or demonstrated degraded performance.

Table 2. Example of intelligent transportation system asset tiers.

Tier 1	Tier 2	Tier 3
• TMS servers • Database servers • Communication servers • Advanced traveler information servers • TMS software • Primary communication media (e.g., truck fiber) • Vehicle detectors • Changeable message signs • Primary communication hardware (layer 3 hub switches) • Over-height vehicle detection systems • Electronic clearance • Traffic signal controllers • Traffic signals heads and hardware	• CCTV cameras • RWIS • Secondary communication media (e.g., branch fibers) • Video wall controllers • Video monitors/projection units • TMS workstations • Secondary communication hardware (e.g., layer 2 switches and edge switches) • Ramp meters • Automated license plate reader cameras	• Highway advisory radio • Weigh-in-motion • Emergency call boxes • Portable signs • Portable detectors • Portable cameras • Connected vehicle onboard units and roadside units

Each agency may consider establishing its own classification system based on what is most beneficial for managing TMS assets. Additionally, an agency may choose to classify each asset in multiple ways that do not conflict with one another. Each classification scheme may serve a specific purpose. For example, an agency may classify TMS assets differently for maintenance purposes versus reporting purposes. A key aspect is to understand the intention behind the classifications and ensure that necessary data are collected to support each classification.

When classifying TMS assets, agencies may also consider shared performance measures for assets with similar classifications. Utah DOT established performance measures and targets for both of its TMS devices and its signal systems. The TMS assets described in the plan fall across three different tiers (TMS software, communication servers, vehicle detectors, changeable message signs, traffic signal controllers (Tier 1); CCTV cameras, RWIS, ramp meters (Tier 2); and Highway advisory radios (Tier 3)).[5]

USING TMS INVENTORY AND TMS RESOURCES

Similar to physical assets, a comprehensive TMS inventory may also include various types of resources that contribute to the system's operation and management. These resources, while intangible, can be important for effective management of the TMS.

The following are examples of TMS resource types and their relevance to the TMS inventory:

- Software: Various software types, versions, and licenses, which may be used for tools such as active traffic management, ramp meter operations, signal timing, and incident management.
- Data: Various data sources such as traffic counts, incident reports, and weather data, which are key to analytics and decisionmaking.
- Policies and procedures: Documentation related to incident response, maintenance of TMS assets, and emergency operations to ensure operational consistency.
- Human resources: Position descriptions, hiring procedures, and performance assessments.
- Documentation: Contracts, invoices, planning studies, and other key documents that support the system.
- Additional resources: Planning studies, procurement documents, deliverable timelines, and any other contract-related resources.

Agencies may consider the following when deciding which resources to include in an inventory:

- Availability of information: Are the data readily available?
- Effort versus value: Is the effort to gather and maintain the data justified by the utility of the data?
- Alignment with objectives: Does the resource align with the agency's overall TMS objectives?
- Update mechanism: How frequently will the data change, and what processes are in place for updating the data?
- Implications if excluded: What are the consequences, if any, of excluding this resource?

PLANNING TO INVENTORY TMS ASSETS AND RESOURCES

When an agency is establishing or updating a TMS inventory, planning is the foundation of creating a meaningful inventory of TMS assets and resources. During the planning process, there are many issues for an agency to consider. This section provides an overview of issues to consider when planning to inventory TMS assets and resources.

TMS Asset and Resource Identification

To initiate the planning effort, it is helpful to first identify which TMS assets and resources will be part of the inventory. Agencies may consider prioritizing assets that directly impact operations and assess the availability and costs associated with retrieving the needed information. It may also be worth considering the asset's value in helping the agency understand asset condition, performance, and needs.

Data Quality and Availability

The planning process may also include considering the quality and type of data available. Existing inventories, both internally generated or collected by external partners, can provide valuable insights. However, the utility of such data will depend on their quality, compatibility with existing systems, and alignment with agency objectives.

Resource Allocation and Ownership

Resource constraints can impact which assets an agency selects for its TMS inventory. Balancing what is selected with available resources is key. Also, understanding the ownership and responsibilities for each asset can assist the planning process. For example, assets managed by contractors may not need to be included in the agency's inventory.

Cohesive Information Management

Collecting and managing inventory information can present challenges. These challenges include understanding what data are required, ensuring consistency of data collection practices, and managing the capabilities of tools used to assist these processes. Agencies may benefit from a cohesive approach that allows them to understand what data they have, where the data are located, and how they can be accessed.

Impact on TMS Operations

Another issue agencies may consider is the extent to which each asset or resource influences important TMS operations. Assets vary in their impact on real-time safety and overall efficiency of the TMS. For example, some assets may play a direct role in emergency response situations, while other assets are used for routine monitoring. Agencies may consider categorizing assets based on their impact on important and time-sensitive operations.

CHAPTER 4. INVENTORYING TMS ASSETS AND RESOURCES

This chapter discusses the specifics of inventorying TMS assets and resources. While there are many TMS assets and resources, the amount of information collected and maintained for each may vary substantially. It is important to focus on information that is useful and obtainable, with the level of effort invested in data collection proportional to the value of the information.

The purpose of this information is to lead agencies through the issues to consider when deciding to pursue and develop an inventory of TMS assets and resources. It builds upon the concepts outlined in chapter 3 and explores the types of assets and resources to consider when planning, developing, or managing an inventory.

The following key topics are addressed:

- Motivation for inventorying TMS assets and resources.
- Data attributes and quality control for inventorying.
- Evaluation of existing inventories and any necessary revisions.
- Considerations for inventory management and maintenance.

Combining asset identification and classification, which typically precede inventorying, this chapter sets the state for an effective TMS inventory. By integrating quality control processes into inventory management, agencies can be better equipped to leverage the inventory information. After reading this chapter, agencies will have a foundation to develop, manage, and use a TMS inventory. This chapter also provides information on how the inventory may be beneficial in monitoring the condition, performance, and management of assets across varying categories, classes, or tiers.

This chapter includes the following sections:

- Motivations for a TMS Inventory. This section addresses why an inventory is used for asset data organization.

- Inventory Management and Maintenance. This section provides an overview of the processes and quality control measures necessary for managing the TMS inventory.

- Data Attributes and Quality Control. This section discusses the data attributes relevant to different assets and introduces quality control methods.

- Data Handling Considerations. This section covers collecting, compiling, and storing inventory data, as well as data formats and automation methods.

MOTIVATIONS FOR A TMS INVENTORY

An inventory is a comprehensive record of an organization's physical assets and non-physical resources, such as asset type, quantity, location, condition, age, and value. One potential motivation for creating an inventory is to use the information to effectively manage assets. An inventory provides the necessary information to make informed decisions about asset maintenance, repair, replacement, and disposal. It is advantageous for agencies to initiate capturing inventory data during initial procurement and then consistently document any modifications made to the asset throughout its lifespan.

Another motivation for creating a TMS asset inventory is its role in asset lifecycle management. Inventory data captured at the point of procurement set a baseline of specifications and expectations. This baseline is beneficial when assessing the impact of maintenance activities or other modifications made to the asset over time. By continuing to track these changes in the inventory, agencies can better understand the evolving performance and condition of their assets. This holistic view can help agencies make informed decisions, whether for routine maintenance or more substantial TMS upgrades.

An additional motivation for creating a TMS inventory is to understand the hierarchical relationships among subcomponents, components, and subsystems. Understanding the asset hierarchy is useful for enhancing predictive analytics and agency decisionmaking. By capturing these relationships in an inventory, agencies gain the ability to identify shared components across the system, streamline reporting, and more thoroughly evaluate performance.

Additionally, the expected operating lifetime of a subsystem may be derived from the expected lifetime of its components and subcomponents. Another motivation for creating a TMS inventory is adopting an intentional classification structure for TMS assets. A standardized classification not only streamlines the collection of similar data for assets in common categories but also facilitates a uniform approach to management. This structure can also reflect performance objectives, asset condition, significance, and other factors, all of which contribute to the requirements of the asset inventory. For instance, for assets in a class anticipated to have high availability and reliability, the inventory could specifically track updates to components.

INVENTORY MANAGEMENT AND MAINTENANCE

Inventory information is useful for managing TMS assets when the information is accurate, accessible, and adequately documents assets and their characteristics. Managing and maintaining an inventory involves ongoing processes to ensure data quality.

Some considerations applicable to managing and maintaining an inventory include:

- Regular data updates: Data in the inventory are regularly updated to reflect changes to assets. Updates can be completed via periodic inspections or other monitoring activities.

- Data verification: Data entered into the inventory are verified for accuracy. Verification can be done by comparing the inventory data with other sources of information, such as maintenance records or inspection reports.

- Data security: Inventory data are kept secure and protected from unauthorized access, which can be achieved through access controls, data encryption, and other security measures.

- Data backup: Inventory data are regularly backed up to protect against data loss or corruption.

- Data analysis: Inventory data are routinely analyzed to identify trends and patterns that may help with decisionmaking.

- Training and support: Staff responsible for maintaining the inventory are trained on how to use the system and given access to technical support when needed.

- Continuous improvement: The inventory management process is regularly reviewed to identify areas for improvement and to ensure it continues to meet the needs of the agency.

Overall, the goal of collecting inventory information is to support the agency in making informed decisions about the management of TMS assets. This includes decisions about maintenance, repair, replacement, and acquisition of new assets.

Identifying Existing Inventory Data

As agencies evaluate the costs of maintaining an inventory, they may consider the impact on other organizational units or contracted entities responsible for asset operations and maintenance. These units may incur additional costs to support the inventory, such as providing data or updating records. Additionally, the costs and benefits might include adding these activities in the work scope of contractors and other departments and how support of these responsibilities may impact abilities and deliveries of other routine activities.

Initiatives focused on agency asset management present opportunities to use current resources and aid in the collection of relevant information pertaining to specific groups of assets. These efforts frequently result in the development of asset management plans that establish and maintain processes for asset management. Regardless of size and scale, these initiatives can offer key input and help drive the establishment of standard attributes for asset inventories. Additionally, these initiatives can facilitate development of repeatable patterns that can be applied in other areas of an agency.

Some inventory information on asset attributes may already exist in agency records. In this case, recording that information is straightforward. However, it may be likely that not all desired assets have been fully inventoried and include all attributes. In that case, the agency may consider identifying gaps between existing and desired asset information.

This is not a complex activity, but it is necessary to complete the process of gathering the inventory information. Once the gaps have been identified, the agency can prioritize the most useful information to obtain first then fill in the remaining items. If the agency had identified a prioritization scheme when determining which assets and attributes to capture, that scheme can be used here to obtain the remaining information. Common information gaps might include older

information such as installation dates, make and model, cut sheet specifications, firmware and software, operating temperature, and other environmental requirements and reliability information such as mean time to failure.

Agencies may find that some of this information is not recoverable. In this instance, the agency could update the inventory to indicate that unsuccessful attempts were made to locate the information and the decision to forego further research. This minimizes the potential for additional resources to be consumed searching for unavailable information.

Identifying Tools

Agencies can use different tools to inventory and manage information on TMS assets and resources. There is no one-size-fits-all solution because not all agencies have the same needs. Tools can be as simple as spreadsheets or as complicated as specialized software or online databases. Many agencies already have at least some mechanisms for capturing and storing inventory information, and often a simple off-the-shelf solution can meet the needs of agencies with limited TMS asset inventories. Data entry of the information is a key element of this process. Whatever tool is used it is helpful if it simplifies gathering, compiling, archiving, and configuring data and managing the use of the information.

When assessing if existing tools can meet the inventory requirements, an agency may consider the following:

- Define the needed capabilities (e.g., action, function, service).
- Examine existing tools to assess whether they meet the needed capabilities.
- Identify what needs to be done to configure or customize the existing tools to fill capability gaps.
- Evaluate whether any gaps that cannot be filled will prevent the agency from addressing its needs.

Information security and data integrity are important regardless of the tool used. Agencies may consider whether it is necessary to restrict access or permissions based on staff responsibility for entering or accessing the data. Limiting data entry and access using basic features, such as drop-down menus, can improve the consistency in the way asset information is entered and labeled.

Most agencies that have inventory tools selected or developed them out of a combination of operational needs and programmatic necessity related to specific requirements. Some agencies have taken an analytical approach to developing tools, while others have followed a more organic approach to adapt an existing tool.

Identifying Resources

In addition to the different tools used to support an inventory, the agency may also consider the resources required to create and maintain the TMS inventory. It is likely that different agency staff and contracted resources may play a role in managing the inventory information.

Different resources can also have different roles in the management of the inventory:

- Resources involved in the initial data collection effort.
- Resources overseeing the tools used to manage the inventory.
- Resources maintaining TMS assets and directly impacting the inventory information.
- Resources accessing the TMS inventory information for reporting or decisionmaking.

Thinking through the various roles required to support an inventory can support overall inventory management. Some agencies may find it beneficial to diagram the data flow, highlighting various roles, responsibilities, and access points.

DATA ATTRIBUTES AND QUALITY CONTROL

TMS asset data comprise various attributes that articulate each asset's unique characteristics. These attributes are cataloged in the inventory and may differ even among assets in the same class. For example, data subsystems could be stored on devices from different manufacturers, using varying technologies, and deployed in different years. These factors, such as age and manufacturer, can influence the asset's performance, maintenance, and management.

For efficient data collection, agencies can develop a strategy that prioritizes collecting the most valuable attributes for managing TMS assets. This strategy may consider the range of attributes associated with these assets and assess the attributes' usefulness in managing the assets. By doing so, agencies can adopt more targeted methods for data collection. Using an attribute grouping strategy offers a practical method for categorizing attributes based on their purpose.

Examples of these groupings include:

- Asset type. This grouping may include basic categorical type of information about an asset. For example, a specific asset may be assigned to one or multiple categories or carry multiple tags. Classification may also assign to hierarchical class (i.e., component, subcomponent, subsystem, or system). Like categorization used in a library to group books by subject, asset classification helps establish groupings and linkages by attribute similarity.

- Asset profile. This grouping collects information that characterizes assets of the same type. For example, asset profile keeps track of products that have a similar make and model and that had been procured at the same time. The profile may include:

    - Make and model.

    - Cut sheet specifications.

    - Firmware and software.

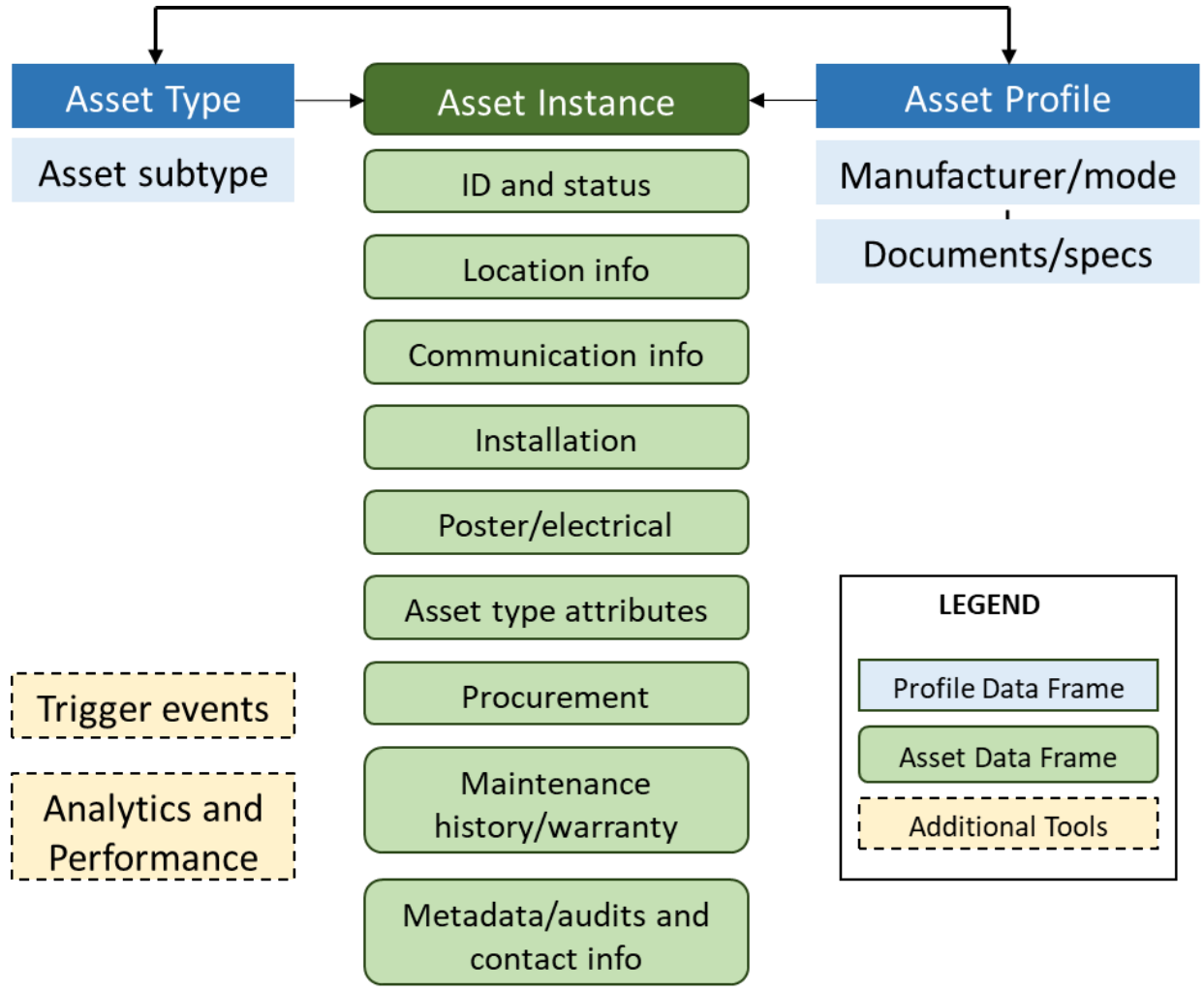
    - Operating temperature and other environmental requirements.

    - Reliability information, such as mean time to failure.

- Warranty information.
- Documentation such as manuals for maintenance and operations, as-built diagrams, testing procedures, and photos.

- Asset instance. This grouping of data represent a specific physical asset that is tracked, stored, or deployed. Two assets that have similar asset profiles can be distinguished by unique instance attributes. Examples of instance attributes may include:
  - Asset identification.
  - Status.
  - Installation/storage location information, such as cabinets or other structures.
  - Communications information, such as the protocols and profiles, including network addresses used to access upload/downloads.
  - Power requirements.
  - Procurement information, such as purchase order, procurement date, and procurement contract.
  - Maintenance schedule and history, including software and data versions.
  - Metadata, such as when asset configuration changed and who made the changes.
  - Contacts for maintenance, operations, and ownership.

Figure 4 illustrates the data frame structure developed by New York State DOT for documenting ITS asset inventory in an ITS asset management system.



ID = identification; info = information; specs = specifications.

Figure 4. Illustration. Asset attribute classification for New York State DOT asset management system.

Table 3 shows an alternative method to associate asset attributes an agency has hypothetically chosen in support of developing an inventory of TMS assets and resources.

Table 3. Asset attributes to include in an inventory.[6]

Area	Attribute	Asset Class			
		Field Devices	Communication and Networking	Hardware/ Software	Portable
Inventory	Functional description	Y	Y	Y	Y
	Make and model	Y	Y	Y	Y
	Serial number	Y	Y	Y	Y
	Specifications	Y	Y	Y	Y
	Quantity	Y	Y	N	Y
	Components	Y	Y	N	Y
	Capital costs	Y	Y	Y	Y
	Contract and warranty	Y	Y	Y	Y
	Status	Y	Y	Y	Y
Location	Physical location	Y	Y	Y	N
	Physical environment	Y	Y	N	N
	Vehicle information	N	N	N	Y
History	Procurement date	Y	Y	Y	Y
	Deployment date	Y	Y	Y	Y
	Performance history	Y	Y	Y	Y
	Maintenance history	Y	Y	Y	Y
	Maintenance and operations costs	Y	Y	Y	Y
	Condition	Y	Y	Y	Y
System Environment	Software and firmware	Y	N	Y	Y
	Hardware	Y	N	Y	Y
	Licenses	Y	Y	Y	Y
Infrastructure	Infrastructure	Y	Y	N	N
	Utilities	Y	Y	N	N
	Enclosures	Y	Y	N	N

Note: Y = yes; N = no; to indicate whether the asset attributes are included in the inventory. Cells containing an "N" are also shaded gray.

To determine which additional attributes to include in an inventory, agencies can implement a prioritization process to aid in data collection. Agencies may also evaluate the cost of compiling the information and the cost to update and maintain the information throughout the life of the asset. Agencies can consider whether, how, and how often the information will be used to achieve organizational objectives and weigh these factors against the cost. Agencies may also consider quality control methods for consistency and accuracy.

Quality control can be considered across various steps of the TMS inventory:

- Planning what attributes to include in data collection."
- Data collection.
- Data validation.
- Metadata, naming standards, system of record, and a consistent distribution tool.
- Data security to ensure controlled access and protection from outside sources.

Another key consideration to ensure data quality is reviewing existing agency processes. Often, small updates to existing processes can ensure asset information is updated as it is changed to maintain data quality. For example, an agency may have an existing maintenance ticketing system to track the maintenance work plan. This ticketing system could be updated to share relevant asset information with the TMS asset inventory.

DATA HANDLING CONSIDERATIONS

The extensive range and variety of TMS assets and the resources required to manage this information calls for early planning in identifying and incorporating different assets into the inventory. Data collection, processing, and storage are important aspects of building and maintaining an effective TMS asset inventory.

The following considerations are key to ensuring the inventory meets the agency's needs and is sustainable over time:

- Basic data attributes: Asset information may include attributes such as make and model, age, location, functionality, and current configuration of hardware and software. Metadata such as users making changes and timing of the changes may also be considered.

- Data collection frequency: Data collection for TMS assets may be done periodically depending on the type of information being gathered and the asset's classification. Static attributes, such as make and model, often require less frequent updates. Assets with important functions may demand more regular inspections and updates to their records.

- Cost considerations: The cost of gathering and compiling pertinent information about assets is key when deciding which asset information to include in the inventory. These considerations may include initial data collection costs and the ongoing cost and resources required to update and maintain this information.

- User focus: Tailoring the inventory to meet different user needs is important. Users may have varying requirements for asset information, and a user-centric approach can help make the inventory more effective and relevant.

- Data consistency: To help ensure data quality, consistency, and accessibility, standardized data collection and recording is key for agencies. This involves adopting consistent approaches across different regions or districts, collecting the same information over time, and gathering comparable data for assets within the same class.

- Data management tools and plans: Agencies may consider the capabilities of the tools used for data collection, storage, and analysis. These tools will influence what data are included in the inventory and how well the data are maintained. Regardless of the tools used, agencies may consider a cohesive plan to manage and access their data efficiently.

CHAPTER 5. DOCUMENTING TMS ASSETS AND RESOURCES

This chapter expands on the discussion of documenting TMS assets and resources in earlier chapters. Documenting is a cornerstone of managing and optimizing the lifecycle of the TMS and TMS assets.

The objectives of this chapter are to provide information on the following key areas:

- Designing and implementing procedures and tools for integrating documented asset information into a TMS inventory.
- Defining and implementing quality control processes to ensure accurate and reliable documentation.
- Integrating asset documentation into daily operations.
- Coordinating documentation efforts with other stakeholders and information sources.

Documentation in this context involves capturing, managing, and updating key information about TMS assets and resources. Key information includes changes to the inventory arising from maintenance, upgrades, reconfigurations, and decommissions of assets. Beyond physical hardware or software assets, agencies may consider documenting resources such as policies, procedures, agreements, procurement documents, and other materials supporting TMS operations.

These resources can play an important role in planning, decisionmaking, allocating resources, and evaluating the performance of TMS assets and an agency's broader TSMO program. Each agency will have its own unique needs for deciding what documentation to include in an inventory.

Factors that can influence these decisions include:

- Who may use the documentation.
- How the documentation might be accessed.
- How the documentation is used to manage and operate the TMS.
- How the documentation supports the TMS or TSMO program.
- What is the agency's capacity to manage these documents and resources.

This information explores an approach to documenting TMS assets and the broader set of resources for agencies that want to initiate and sustain documentation in support of their TMS and TSMO program goals. This approach encompasses identifying documentation needs, assessing current capabilities, planning for enhancements, and other issues agencies may face during the documentation process.

This chapter includes the following sections:

- Comprehensive Inventory of TMS Documentation and Resources. This section specifies what kinds of resources and information may be included in the inventory, beyond TMS assets. This section covers resources such as policies, procedures, and associated documentation.

- Documenting TMS Asset and Resources Throughout Their Lifecycles. This section emphasizes the value of capturing detailed information at every lifecycle stage, helping agencies make informed decisions, optimize performance, and plan for future needs.

- Identifying Gaps in Documentation of Inventory. This section discusses the challenges of documenting assets, highlighting the need for a systematic approach to identify and prioritize documentation. It discusses how to use a gap analysis during inventory creation to determine what documentation exists and what might be missing. This section also suggests effective practices for handling missing or corrupt information.

- Incorporating Documentation into Inventory Processes. This section describes the role of incorporating documentation as a part of TMS inventory management. It offers insights on when to consider documentation and updates to the inventory as part of other agency processes.

- Challenges and Issues to Consider. This section discusses the challenges an agency may face when documenting TMS assets, focusing on the need for comprehensive documentation covering asset condition and performance. This section identifies key challenges, such as establishing documentation standards and control, and discusses aligning documentation efforts with inventory processes and other existing agency efforts.

COMPREHENSIVE INVENTORY OF TMS DOCUMENTATION AND RESOURCES

Documentation starts with capturing, managing, and maintaining detailed information about the TMS assets. It also includes a comprehensive set of resources and information that contribute to effective TMS operations. The goal is to provide agencies with a roadmap for initiating and sustaining a more inclusive inventory that integrates both physical assets and intangible resources. The key to this is understanding which resources to include in the TMS inventory.

An agency may consider resources they use to manage, operate, maintain, monitor, evaluate, and report on the performance of TMSs. Operational policies, standard operating procedure documents, and device documentation are important to the overall TMS performance. Tracking changes to these resources over time enables a historical view, offering insights into past versions and changes over time.

As an example, an agency may have transitioned its ramp metering system from local control or semi-coordinated operation to a fully dynamic, traffic-responsive operation. This significant shift may likely involve introducing a new operating procedure and a corresponding software module, both of which impact how the ramp metering system functions. Such procedural and software

changes include documentation about the details of their initiation and operations. Including these resources in the TMS inventory ensures the agency has a comprehensive view of both the assets and the resources impacting operations.

Agencies may also think about the TMS lifecycle, considering what resources will be needed at each phase, from procurement to maintenance to retirement. Before navigating the complexities of TMS asset documentation and resources, it is beneficial to review figure 2, which shows an overview of a typical TMS lifecycle. The next section discussed the value of documenting assets and resources at each lifecycle stage.

DOCUMENTING TMS ASSETS AND RESOURCES THROUGHOUT THEIR LIFECYCLES

Comprehensive documentation provides agencies with insights for decisionmaking, planning, and making future improvements. The following sections provide insights into the documentation process, from asset procurement to replacement, and highlight documentation an agency may consider including in their inventory.

Asset Procurement Process

Any asset an agency procures is acquired to perform a certain function or set of functions. These functions are typically defined in a series of requirements or specifications. From there, the agency may choose to conduct a competitive procurement process or select the asset from a qualified provider. In either circumstance, the agency will have evaluated its options and selected the supplier whose product best fits the requirements within the cost constraints defined as part of the process.

Documentation of the procurement process—particularly the requirements defined and used for evaluation—provides agencies with important contextual information. Specifically, during the procurement stage, technical specifications are important documents. This documentation likely includes functional capabilities, interoperability standards, and target device performance measures. This information guides the inventory process by ensuring the agency can assess how well it had managed the process, how relevant the requirements were, and whether adjustments might be necessary moving forward.

Asset Installation and Setup Process

Once an asset has been procured it is usually delivered, installed, configured, tested, and activated. Capturing information for each of these steps helps inform an agency’s current and future actions.

Delivery documentation can include invoices, shipping information, validation that the asset was received intact and undamaged, agency storage environment, and internal handling. This information is important for supporting warranty claims that may arise during the life of the asset. This information also offers the agency an opportunity to correct issues and improve internal processes if problems surface.

Installation documentation can include the name and organizational affiliation of the installer; installation method used; connections established with power and other devices; checks performed during installation to confirm functionality; and post-installation inspection for security, safety, and other characteristics important to the agency. This documentation is also useful for warranty purposes, and it provides evidence to procurement staff, testers, and operators that the asset was installed as specified by the vendor. Installation documentation also provides evidence that all appropriate checks were performed during and after installation.

Capturing configuration details during and after installation is important for an agency to confirm the appropriate steps were taken to ensure optimal asset performance. Capturing this information also enables the agency to coordinate with the vendor, if the need arises, to troubleshoot and correct issues or to update configuration information as the asset matures through its lifecycle.

During the asset installation phase, agencies may consider creating and saving an installation report, which includes:

- Installation date and time.
- Staff or contractors involved.
- Photographs or schematics of the installation.
- Specifications of any connections made, such as power or communication networks.
- Initial configuration settings.
- Security or safety inspections.

Once the asset has been installed and configured, it is typically tested by the agency prior to being fully activated to confirm the asset is operating properly and within specifications. This testing often consists of acceptance testing and integration testing. Acceptance testing is conducted to confirm the asset is performing in compliance with requirements and specifications and is typically at least one component of the process to evaluate whether the vendor is compensated. Integration testing is used to confirm the asset is performing correctly within the larger TMS systems environment. The procedures used, the associated test equipment and personnel, and the results of these tests are all important to document for both contractual compliance and to inform future operations, maintenance, and asset testing activities.

Asset Operation and Maintenance Process

It is common for assets to evolve during their operational lifetimes. Adjustments are made, configurations are updated, usage details are changed, and maintenance is conducted through the lifecycle. At each event, agencies determine which information to document. A service order, often referred to as a ticket, typically captures relevant details when an asset malfunctions or undergoes damage. These details may include the reason for the order, troubleshooting actions, diagnostics performed, tools used, and the asset's final configuration.

Regularly tracking a device's preventative maintenance schedule, failures, and executed work orders offers a more comprehensive view of the asset condition. Such documentation serves as a historical record, capturing the asset's progress through its lifecycle. A link to that actual service

order, whether for periodic preventive maintenance or for corrective action, enhances traceability to organizational processes, procedures, and staff resources.

For example, an agency's maintenance ticketing system may automatically log details as maintenance is performed. Utah DOT's Asset Information Management System links asset inventories to their work order system.[1] Each logged ticket or work order may include a unique record that can be tied to the asset inventory's historical record. This record could include details such as personnel involved, dates and times, actions taken, parts replaced, and photographs.

Asset Replacement Process

As an asset approaches and reaches end of life, agencies might collect and review specific data to inform the procurement of next-generation assets. Relevant documentation may include lessons learned during the asset's lifecycle, such as procurement challenges, installation issues, operational inefficiencies, and maintenance gaps. This information can inform better selection for new assets. Agencies might also benefit from maintaining historical asset lifecycle records. For example, documenting recurring issues with an older model of a network switch could lead an agency to prioritize different features or seek different vendors for its replacement.

IDENTIFYING GAPS IN DOCUMENTATION OF INVENTORY

Establishing the gap between existing and required documentation is often part of the inventorying process. This is a key step to figure out what asset-related information is important and currently missing from the inventory. Agencies may start this gap analysis by first evaluating the value and priority of the documentation, drawing upon the asset and attribute prioritization identified in earlier stages.

Understanding what to document begins with an assessment at the inventorying stage. Agencies review existing inventory information to identify which assets have already been accounted for and which assets might be missing. This review also informs the types of documentation that are beneficial to collect and include. The gap analysis helps determine if important documents, such as maintenance manuals, as-built diagrams, testing procedures, and photographs, are available or missing.

Common areas for identifying documentation gaps may include:

- Inventory status: Are all key assets included in the inventory?
- Document management: Are existing documents adequately managed and configured for easy retrieval and updates?
- Accessibility: Can agency staff easily access and use the documented resources?

If specific documents are missing or unrecoverable, agencies may update the inventory to indicate that unsuccessful attempts were made to locate the missing information. In doing so, agencies can avoid wasting additional time and resources in the future. The outcome of a gap analysis serves two purposes. First, it updates and enhances existing inventory with needed documentation. Second, it helps agencies compile new, necessary documents and resources.

INCORPORATING DOCUMENTATION INTO INVENTORY PROCESSES

The process of inventory management is incomplete without a systematic approach to documentation. Incorporating documentation not only provides a historical record but also aids in future enhancement efforts. This section provides insights into how an agency might incorporate documentation into its inventorying processes, or how existing agency processes can be updated to capture documentation changes as they take place. Incorporating documentation starts with the initial gap analysis to determine what kinds of records are already available and what records are missing.

The gap analysis allows agencies to:

- Identify currently available documents and their relevance.
- Determine any important but missing documentation.
- Prioritize collecting key documents.

Keeping the inventory up to date with real-time documentation is key. As changes to assets occur, whether through upgrades, repair, or replacement, agencies may want to record these updates in the inventory documentation. Strategies for this include:

- Updating existing processes to add a step for documentation updates following any asset changes.
- Leveraging existing tools or systems to automate these updates where possible.

Agencies may also consider a common database for all captured information—one that relies on a single data structure and data dictionary and is accessible and usable regardless of the interfaces used to collect or retrieve the information contained in it. A database that will remain viable over the long term may also be a good choice. Another important consideration is whether to leverage an existing database, procure a commercial off-the-shelf product or service, or develop a custom-built tool. As with any technology solution, agencies will need to consider trade-offs. These include such items as those highlighted in table 4.

Table 4. Characteristics of purpose-built versus common software tools for documenting traffic management system assets.[(1)]

Commercial Off-the-Shelf Systems	Custom Tools
Predefined database and user interfaces	Need to create database and user interfaces
Limited customization confined to provider	Fully customizable by the agency
Developed to leverage prior user experience and lessons learned by multiple customers	Developed to meet specific needs of the agency
May be rapidly deployed	May require a lengthy development process
May have more upfront costs	May require more staff or contracted resources to build

Selecting the appropriate tools is key for integrating documentation into the inventorying process.

Agencies may consider tools that:

- Facilitate capturing and storing both asset and document information.
- Can be accessed by a diverse range of agency roles, from operations to information technology (IT) support.
- Have approachable user interfaces that users will encounter for data entry, access, and reports.
- Allow for real-time updates to maintain a current and comprehensive inventory.
- Provide access to different stakeholders within the agency, such as asset managers, support staff, or agency decision makers.

CHALLENGES AND ISSUES TO CONSIDER

Challenges associated with documenting TMS assets and resources are similar to those of inventorying because the activities are similar. Both rely on using well-documented procedures supporting the incorporation or updates that may occur for each asset or resources, which involve documents an agency decides to include in an inventory. This section discusses considering what documentation currently exists, what changes may be needed for improvement, challenges in integrating documentation with the inventory, and challenges with incorporating these practices into other existing processes and initiatives.

Considering the existing state of asset documentation within the agency introduces a few issues:

- Completeness and accuracy of existing documentation.
- Disparate storage locations and varying standards.
- Lack of integration between existing documentation and inventory systems.

Identifying gaps and needed documentation to include in the inventory introduces additional issues:

- How often a gap analysis is reviewed.
- Availability of obtaining required documents.
- Impact of documentation on ultimate asset performance.

Once an agency has decided to capture more documentation and integrate into the TMS inventory, the agency may initiate a project to fill documentation gaps.

This can present other issues for the agency to consider:

- Demand on agency resources or the requirement of contracted support.
- Training programs for staff who are responsible for collecting documentation.
- Potential investment in tools or technology to support the effort.

After identifying and collecting the updated documentation, the agency may integrate this documentation into its existing inventory.

This process introduces a few additional issues:

- Updates to existing processes for how documentation updates trigger an inventory change.
- Quality assurance processes to verify inventory and documentation data quality.
- Adoption of relevant IEEE standards or ISO 9001:2015 standards for documentation control.[7,8]

Table 5 consolidates some of these challenges and provides a risk assessment of their likelihood and severity for agencies to consider. The table also suggests opportunities and mitigation strategies for addressing these risks. Agencies may use this information to support decisionmaking when accepting, mitigating, or resolving the identified risks associated with documenting TMS assets and resources.

Table 5. Documentation challenges and issues.

Challenge/Issue	Likelihood	Severity	Opportunity/Mitigation
Documentation standards; as it relates to TMS assets, there is no complete *de facto* standard to follow	High	Medium	Investigate IEEE standards[7] and adopt those that are applicable
Creating a list of commonly needed documents	High	Medium	Work backwards from intended use of the documents and 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[8]
Creating process documentation	Medium	Low	Creating a step-by-step list of all steps required to maintain important documents.
Staffing and responsibilities	High	High	Simplify responsibilities, identify clear owners, and explain the importance of each task.
Inventory integration across various subsystems and platforms	Medium	Low	Where possible, integrate systems to encourage automation of updates or quality assurance verification.

CHAPTER 6. CONFIGURING TMS ASSETS

CM practices can be beneficial for maintaining an accurate, up-to-date, and reliable TMS asset inventory. CM involves the systematic control of changes to the configuration of an asset throughout its lifecycle. Integrating TMS inventory information into an established CM process is key for maintaining records of asset configuration.

The *Configuration Management for Traffic Management Systems* report advocates for a unified CM process that may employ different techniques or activities.[3] This chapter explores the connection between TMS asset inventory management and CM procedures and practices, focusing on practical steps and considerations for integrating TMS asset inventory information into this unified CM process.

The objectives of this chapter are to help agencies:

- Select and configure information for the TMS inventory.
- Integrate TMS inventory information into a CM process.
- Identify gaps between what the inventory holds and what is needed for effective CM.
- Create strategies for developing or adapting tools and databases to support CM activities and techniques for the inventory and its information.
- Incorporate quality control process specifically designed for the management of TMS inventory information within CM.
- Integrate configuration process into daily maintenance and operations activities supporting a TMS inventory.

CM is defined as a series of process and procedures to establish and maintain system integrity.[3] The goals is to ensure the inventory remains up to date and maintains its integrity during system changes.

The concept of system integrity is evident in an inventory that is:

- Well-defined and well-documented, consistent with the previous chapter on documentation.
- Always available as a working baseline for implementing and delivering traffic management services.
- Capable of seamless integration with other systems.
- Characterized by a high degree of traceability, enabling easy identification of how system functions are provided technically.[3]

A main objective of CM is to establish consistency of an asset's attributes throughout its lifecycle. Consistency is achieved by integrating changes and accompanying documentation directly into the TMS inventory. The result is a comprehensive and dynamic inventory that allows for control over system changes and documentation.

The relevance of incorporating CM into TMS inventory management may include:

- Ensuring that documentation accurately aligns with the actual physical and operational design of the item.

- Ensuring project traceability, which serves as an audit trail explaining the current state of the system and its alignment with the TMS inventory.

- Enabling disaster recovery efforts to revert to a well-established, inventory-supported baseline.

Benefits for agencies applying CM to their TMS inventories may include:

- Improved system maintainability and reliability, safeguarding the integrity of the TMS inventory.

- A coordinated approach to system upgrades and expansions, effectively managed within the inventory.

- Enhanced interoperability, facilitating information sharing and system integration, which in turn enriches the TMS inventory.

CM can be incorporated into many activities, support contracts, or services related to a TMS. This helps ensure that modifications, such as maintenance or software updates, always align with the inventory. Implementing a CM process may assist agencies in managing changes, navigating interdependencies among software and hardware assets, and maintaining an agile TMS inventory. The remainder of this chapter provides information about how agencies can selectively integrate CM activities and techniques into the management and upkeep of a TMS inventory.

This chapter includes the following sections:

- Configuration Management Process. This section provides an overview of CM process and activities, evaluating which practices can be specifically integrated with the TMS inventory.

- Implementing Configuration Management Activities. This section provides actionable tasks and information for using CM techniques in the context of TMS inventory management.

- Identifying Gaps. This section discusses how agencies can review current processes to identify additional resources or plans that may be required for TMS inventory management.

- Challenges and Issues to Consider. This section identifies issues or challenges an agency may face when integrating CM into TMS inventory management, along with suggested strategies for mitigating or addressing these challenges.

CONFIGURATION MANAGEMENT PROCESS

This section introduces CM process and techniques most relevant to TMS inventory management. The goal is to evaluate how an agency can leverage the CM process, activities, or techniques to enhance TMS inventory management.

This section discusses the following CM activities:

- CM plan: Laying the foundation for an effective inventory management process, activities, techniques, and support resources.
- CM baselining: Establishing a point of reference for all TMS assets.
- CM library: Creating a consolidated repository of important documentation and instructions.
- CC or change management: Managing and authorizing changes to TMS assets.
- Configuration history: Logging the lifecycle of each asset for auditability and traceability.
- CI: Enabling each asset to be uniquely identified for tracking.
- CSA: Providing a reliable log of asset statuses for future reference and analysis.
- Configuration audits: Verifying that inventory configurations match the documentation.

Configuration Management Plan

A CM plan is a central source of information for the CM program or initiative, describing how CM is accomplished and how consistency between a system's configuration and the configuration records is achieved and maintained. The plan documents the CM process and serves as a tool to gain project and management support for the process. It also acts as a key document that defines all procedures, responsibilities, and tools to be used within the CM process.

Incorporating CM policies, activities, and techniques into a TMS asset inventory ensures the inventory is consistent, accurate, secure, and readily available for decisionmaking. A well-executed CM plan tailored to the specific requirements of TMS assets provides a structured framework that aligns with the agency's goals for its TMS inventory, resulting in a higher degree of reliability.

Developing a TMS-focused CM plan involves intentional effort to ensure the plan meets the needs of the TMS. The following list summarizes the steps for developing CM plans recommended in *CM Plans: The Beginning of Your CM Solution* and *Configuration Management for Transportation Management Systems*:[7,3]

- Establish inventory objectives: Prioritize what the agency wants to achieve with the CM plan within the broader goals of the TMS inventory.
- Choose a standard: Select a proven standard, such as the *IEEE Standard for Software Configuration Management Plans*, to inform the CM plan development.[10]
- Create a TMS-specific template: Create the template to reflect the unique attributes and needs of the TMS inventory.
- Develop CM procedures: Collaborate with key TMS and CM stakeholders, using the template, to develop procedures tailored to the agency's TMS inventory needs.
- Document procedures: Document the procedures devised, focusing on TMS asset integration.

The following sections describe examples of CM plan components and procedures.

Configuration Management Baselining

At the onset of the TMS, when an inventory is created, the agency may consider developing a baseline of information for its TMS assets. A baseline provides a snapshot of the current status of TMS assets, serving as a key point of reference for inventory management activities and reporting. Baseline information can assist in diagnosing and correcting issues that appear, and it is beneficial to align the baseline conditions with the inventory management goals, such as auditing or expanding the TMS inventory.

For CM, a baseline is a stable, well-documented, and thoroughly tested version of the TMS at a specific point in its lifecycle.[3] A baseline includes all known configuration information for the TMS assets at the time configuration is conducted. Applying CM to the TMS inventory and its baseline may support comparing future changes and allow the agency to revert to prior configurations if serious issues arise with system function once a new configuration has been implemented. This is particularly beneficial when major new systems, subsystems, or classes of assets are deployed and integrated into the TMS.

Baselining can be established at various stages in the development, implementation, and operation of the TMS.

The following are examples of baseline products which may be included and configured in an inventory:

- Concept of operations baseline: Established at the conclusion of the system conception stage, this baseline sets initial requirements for the TMS and is key for determining the types and quantities of assets needed for the initial inventory.

- System baseline: Usually considered the final functional requirements developed for the system, this baseline outlines asset types and configurations and helps avoid unwanted changes or scope creep in the TMS inventory.

- Development baseline: This baseline documents detailed design information to inform building or acquiring TMS assets and ensures the inventory matches planned specifications.

- Product baseline: Reflecting the system as built, this baseline acts as a snapshot of the inventory at the time of system completion.

- Operational baseline: This baseline documents ongoing changes in the TMS and is important for keeping the TMS inventory current and optimized for performance.

The baseline of these products directly support the development, management, and maintenance of a TMS inventory. They serve as a tool for ensuring inventory accuracy, planning for asset upgrades, and making informed decisions regarding inventory management. Careful attention to establishing formal baselines can ensure long-term system availability and supports efficient future system maintenance, integration, and upgrades.

Configuration Management Library

A CM library is the authoritative source for all CM activities and directly supports real-time inventory management. A CM library allows an agency to identify, prepare, and integrate key information, documents, and procedures. Examples include operations, maintenance, and system recovery procedures; roles and responsibilities; governance documents; validation criteria; change control forms; work orders; baselines; and retention policies and backup procedures targeted to the TMS assets and TMS asset inventory. If an agency does not have a preexisting CM effort, initiating a CM library is a foundational step for an agency to properly manage its TMS inventory.

Configuration Control

CC is a methodology which may be used for managing changes to the TMS assets. The intent of CC is to ensure that configuration changes are justified, approved, and implemented according to prescribed organizational policy and sound systems engineering principles. It ensures that any modifications are justified, approved, and verified, offering an important layer of oversight to management of the TMS inventory.

Core CC components include:

- Baseline change protocols: Procedures for changing existing baselines in TMS assets.
- Change request procedures: Steps for submitting, logging, evaluating, and approving asset changes.
- Responsibility assignment: Assigns which organizational units and staff oversee change control.
- Change control board: Establishes who is responsible for final approvals and validating procedures.

Configuration information is a key component of an asset inventory. Asset location and status, and associated performance documentation, are incomplete without a well-documented CM program that captures and maintains this information. A comprehensive TMS asset inventory may include physical assets themselves as well as their configuration details, which are managed through CC. As with inventorying and documenting, deciding what configuration information to capture and retain can be challenging. However, it is a straightforward exercise that focuses on capturing and using the following categories of information. Incorporating CC into TMS inventory management fills gaps left behind from simple asset tracking. It provides a more complete picture by ensuring full configuration details are included and maintained in the inventory.

The following asset categories in the TMS inventory may be influenced by CC:

- Hardware: detectors such as loops, radar units, wireless communication devices, signal controller cards, signal heads, message signs or modems.
- Software: software drivers, decision support systems, databases, algorithms for data analysis, video analytics detection, and firmware embedded within hardware components.
- Settings: sensitivity settings, timing plans, and device update rates.

Configuration History

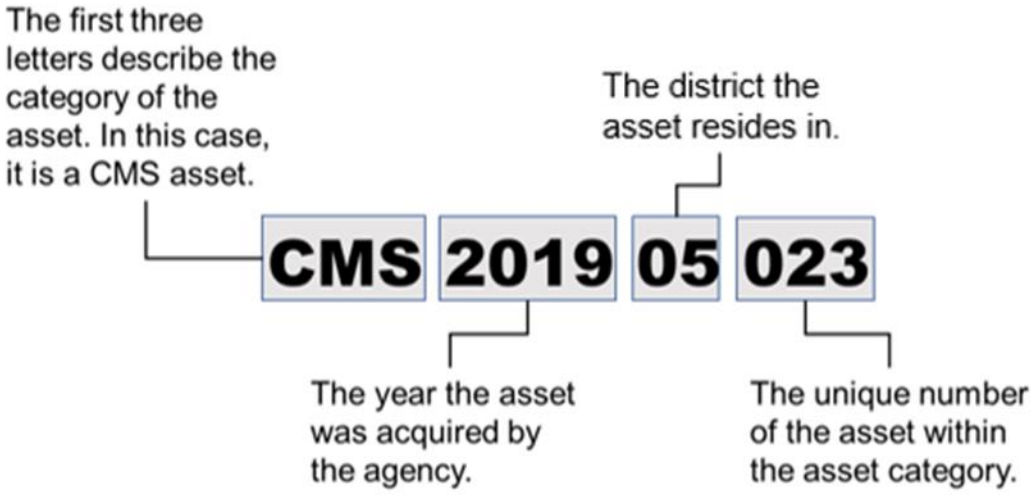
Configuration history is a comprehensive record that captures all changes made to the TMS assets throughout their lifecycles. It is an accountability and reference tool, providing historical context to the state of each asset at any given time. Configuration history complements a TMS inventory by adding a temporal dimension to each asset. It fills the gap between the asset's current configuration and past configurations, which aids in troubleshooting, performance analysis, and long-term planning efforts.

Core components of configuration history include:

- Change details including the nature of the change and any associated documentation.
- Version information capturing configuration or version numbers.
- Change justification notes with reasons for any upgrades or corrective actions.
- Approvals to document who authorized any changes.
- Exact date and time when a change occurred.
- Identification of the staff responsible for executing the change.

Configuration Identification

CI refers to the process of creating and maintaining the full documentation of the items being configured. Tasks performed as part of CI include item naming, drawing, document management, information management, and baselining. Agencies may consider starting with a review of unique asset identification procedures. An example identification structure for a changeable message sign is shown figure 5.



CMS = Changeable Message Sign.

Source: FHWA.

Figure 5. Illustration. Unique asset identification composition.

The key is to ensure that each individual asset can be uniquely identified. This is important to align all configuration information with the asset, since not all assets within a class may have been configured the same. As long as each asset can be individually identified, the remaining information can be associated with it regardless of the tool used to store configuration data.

Configuration Status Accounting

Configuration Management for Transportation Management Systems offers information about CSA, which is a systematic approach for capturing, storing, and managing all details about items that are part of the configuration base.[3] This includes tracking changes over time and maintaining a historical record for each asset.

CSA is responsible for the storage and maintenance of:

- Configuration documentation.
- Item documentation.
- Operational and maintenance documentation.
- CM process details.

Some of the primary objectives of CSA include allowing access to information about change control decisions, supporting system inquiries such as design problems, and providing total information about a configuration items. CSA allows the TMS to backtrack information to discover the source of problems or issues that may arise operationally.

Configuration Audits

Configuration audits confirm that designs or documentation achieve their goals by systematically comparing the requirements with the results of tests, analyses, or inspections. Configuration audits are thorough examinations of CIs, comparing the associated documentation and change records that provide a history of the item to ensure that documentation reflects the current state of the CIs. A primary objective of configuration audits is verifying that documentation for items is consistent with the items themselves. Audits are carried out to assure that change control procedures in place are effective and are being used, and that documentation reflects actual changes. Audits typically are carried out by the organization or by an independent contractor.[3]

Configuration audits analyze and verify that configuration items and their documentation reflect the current situation and if changes had been carried out as approved by the administrative body. Agencies using change control ensures change has been implemented in an orderly and controlled way. Configuration audits add an extra layer of quality by verifying correct implementation of any identified changes.

According to EIA Standard 649, audits can be planned and executed with:[11]

- Audit plans that clearly outline the agenda, personnel involved, procedures, and items to be audited.

- Audit personnel who are selected based on their expertise in the audit material.

- Relevant documentation including design documents, identification data, and change history.

- Audit tools such as software or matrices to assist in verifying alignment between design and documentation.

IMPLEMENTING CONFIGURATION MANAGEMENT ACTIVITIES

Effective TMS inventory management is key for agencies that want to use the information to operate their system effectively or upgrade their TMS assets. A CM process, activities, and techniques can offer a systematic approach to manage this complexity.

This section discusses how agencies can leverage CM in the following stages of TMS inventory management:

- Starting a TMS inventory from scratch.
- Updating an existing inventory.
- Sustaining TMS inventory quality over time.

When starting an inventory from scratch, agencies may consider the following CM processes to support their efforts:

- CM plan: The CM plan is key for initial planning. Agencies can start by creating a comprehensive CM plan to outline the objectives, stakeholders, and procedures for TMS inventory management.

- CM baselining: Establishing a baseline configuration for all initial TMS assets serves as a point of reference for future updates and audits.

- CI: It is important to uniquely identify each asset for ease of tracking and management. This process supports all future stages of inventory management.

- CM library: A consolidated library can be created to store key documentation, user manuals, and configuration information for all TMS assets and resources.

When updating an existing inventory, agencies may consider the following CM processes to support their efforts:

- CC or change management: Once an inventory is in place, managing and authorizing changes becomes key. Agencies may implement a change management process to evaluate, approve, and document all changes to TMS assets.

- Configuration audits: Agencies may conduct periodic audits to verify that the actual configurations of assets match the documentation and immediately address discrepancies.

- CSA: Agencies can maintain a reliable log of the statuses of all assets, updates, and changes. This log can be invaluable for future reference and for audits.

When sustaining their TMS inventory long term, agencies may consider the following CM processes to support their efforts:

- Configuration history: Agencies can maintain a detailed log of the lifecycle of each asset, including any changes, updates, or decommissioning activities. This allows for both traceability and auditability.

- CSA: Agencies can continually update the status log to reflect any changes in the configurations or statuses of assets. This helps to quickly identify discrepancies or issues that may arise.

- Configuration audits: Agencies can conduct regular audits to ensure that configurations remain compliant with the baseline and any new standards that may have been established.

IDENTIFYING GAPS

Agencies can use CM for software, hardware, databases, computer hardware, communication devices, and field equipment that are part of their TMS. CM practices can play a key role in identifying gaps in a TMS inventory, whether the agency has an established inventory or is initiating a new one, or ensuring an inventory remains current.

Before diving into the CM process and what practices may support managing a TMS inventory, agencies may want to assess their existing inventory and what CM practices may already being used. While the information on physical assets may be straightforward to capture, some software-related data and configuration history may be more challenging to collect. Agencies may need to consider only capturing the configuration data that align mostly with their TMS program objectives and available resources.

Factors to consider when deciding how to go about developing these priorities include:

- Functional criticality: Prioritize assets that are functionally critical for the TMS or support high-priority TMS operations. Such assets may include traffic signal controllers whose failure could have significant impacts on traffic safety and flow.

- Asset age: Prioritize assets based on their lifecycles. Assets closer to retirement may be a lower priority while brand-new assets are more likely to be included in the CM process.

- Asset complexity: More complex TMS assets may require more rigorous CM. Agencies may need to consider the level of effort required based on the asset and compare this to available resources.

- Information availability: Agencies may face challenges in finding enough configuration information for older assets. If so, the agency may decide if further research is worth the effort based on other prioritization factors.

For agencies without an existing TMS inventory, the lack of structured asset information can lead to several potential gaps:

- Information fragmentation: Asset information may be informally tracked across disparate departments, resulting in fragmented and unreliable data.
- Compliance issues: Lack of formal tracking can lead to regulatory compliance issues.
- Operational inefficiency: Decisions based on incomplete or outdated asset information can impact system performance.

CM processes can help address these gaps in many ways. For example, developing a CM plan lays the groundwork for capturing all necessary asset information in a centralized manner, ensuring that everyone adheres to the same procedures and standards. CI helps uniquely identify assets, standardizing how each asset is tracked and monitored. Regular configuration audits can help justify the need for more resources by highlighting inefficiencies in the existing setup and by demonstrating how a formalized inventory can lead to better asset utilization and compliance.

For agencies with an existing TMS inventory, maintaining the quality of existing data can introduce the following challenges:

- Data obsolescence: Asset data can quickly become outdated due to hardware upgrades, software updates, and other changes.
- Inconsistent updates: As staff changes or departments are restructured, the consistency of inventory updates can suffer.
- Resource allocation: Periodic audits and reviews require dedicated resources, which might not always be available.

CM processes can offer sustainable solutions to these challenges. CC ensures that any change to TMS assets is carefully reviewed, approved, and documented, thus maintaining the integrity of the inventory data. A detailed configuration history log allows the TMS to backtrack information, helping to discover the source of problems or verify the effect of changes over time. Configuration audits can be scheduled periodically to verify that the existing inventory matches the actual assets in use. This not only ensures compliance but also justifies the continued resource allocation for inventory management.

CHALLENGES AND ISSUES TO CONSIDER

The task of developing and sustaining an inventory of TMS assets through CM introduces unique challenges and issues to consider. Implementation of the right processes at the right time and maintaining the CM process and applicable practices throughout the asset lifecycle are key.

Table 6 provides a summary of challenges and issues an agency may encounter when developing, initiating, or maintaining CM practices to either create a new TMS inventory or improve an existing one. By recognizing these challenges early and proactively seeking mitigation strategies, agencies can increase the likelihood of successful implementation of their TMS inventory through CM practices.

Table 6. Challenges and issues in developing and sustaining a traffic management system inventory through configuration management.

Challenge/Issue	Likelihood	Severity	Opportunity/Mitigation
Initiating change control boards	High	High	Gain support from upper-level management; showcase the high cost of poor change control
Developing efficient CM processes for inventory	Low	Medium	Consider all required resources, policies, and tools
Adhering to CM process and procedures	Medium	High	Enhance quality control with regular configuration verification and audits
Staffing resources for TMS inventory management	High	High	Allocate tasks within existing roles; incorporate staffing needs into a broader TMS plan
Overcoming slow user acceptance	Medium	Medium	Prioritize user-friendly tools and introduce only the necessary processes
Delaying CM implementation in TMS inventory lifecycle	Low	Medium	Implement CM practices as early as possible and sustain them throughout the system's lifecycle

CHAPTER 7. INCORPORATING INVENTORY PRACTICES INTO MANAGING AND OPERATING A TMS

This chapter identifies opportunities for agencies to incorporate inventory management of assets and resources into the management and operations of their TMSs. This information explores how different processes, practices, and activities across lifecycle phases use information from an inventory and facilitate updates to ensure inventory accuracy. For example, agencies may include leveraging asset information in day-to-day operations, applying quality control to maintenance processes to validate inventory information, or using the inventory to make informed decisions for future upgrades.

The objectives are to:

- Identify practices for agencies to consider when updating, maintaining, and using an inventory of TMS assets and resources.
- Highlight opportunities for agencies to integrate documentation practices into management and operations of their TMSs, with a focus on adding or updating inventory information.
- Explore methods for agencies to consider incorporating change control and other CM practices into managing and operating TMSs, with a focus on how these practices contribute to maintaining an accurate and up-to-date inventory of TMS assets.
- Provide examples of how agencies can use the inventory information to benefit TMS operations.

This chapter contains the following sections:

- Incorporating Inventorying Practices into TMS Management and Operations. This section discusses the benefits of including inventorying practices in the lifecycle processes of a TMS.
- Incorporating Documentation Practices into TMS Management and Operations. This section discusses the importance of maintaining accurate and up-to-date documentation with a TMS.
- Incorporating Configuration Management Practices into TMS Management and Operations. This section examines the role and benefits of CM in enhancing the TMS.
- Using the Information for TMS Operations. This section discusses how accumulated asset condition data can be leveraged to optimize TMS operations.
- Identifying Agency Resources. This section discusses TMS practices in identifying agency practitioners who contribute to inventorying, documenting, and CM efforts.

- Challenges to Consider. This section highlights potential issues an agency may face when implementing inventorying, documenting and CM practices into TMS operations.

INCORPORATING INVENTORYING PRACTICES INTO TMS MANAGEMENT AND OPERATIONS

Incorporating inventorying practices into the management and operations of a TMS can offer benefits to an agency. Many TMS lifecycle processes can benefit from inventorying practices. At the self-assessment phase, a comprehensive inventory of existing assets can provide baseline data that feed into a capability maturity framework. This information can help agencies determine current capabilities, identify gaps, and develop targeted improvement action plans.

During any strategic planning phases, inventory data, such as asset age, can inform the development of a multiyear strategic plan. This information can also be used to support and shape the agency TSMO program plan or TMS plan. When conducting feasibility studies, agencies could consult the inventory to determine the need for asset upgrades or replacements, which informs the planning and designing of new initiatives. During project development or procurement phases, agencies can incorporate newly acquired assets into the TMS inventory. This can ensure that asset specifications, configurations, and statuses are tracked.

As agencies allocate resources to manage and operate different facets of their TMSs, these decisions can benefit from robust inventory practices. Automated protocols could flag assets nearing the end of life if the data have been captured and included in an inventory. Real-time inventory data feed into TMS monitoring and reporting capabilities. This allows agencies to make more informed decisions in realtime and during long-term planning efforts. Without up-to-date inventory information, these decisions are more difficult to make.

A feature of inventorying TMS assets and resources involves the real-time monitoring of TMS asset statuses within the system. This type of monitoring can serve as a proactive tool for agencies, enabling them to initiate timely responses for replacements or asset maintenance based on ongoing performance metrics. When performance issues are detected, the monitoring system can automatically generate recommendations and insights.

These insights can be used to upgrade the TMS inventory information or inform other priority agency initiatives, such as preventive maintenance efforts to address issues identified from monitoring asset conditions. Maintenance and repair activities directly impact inventory information. As assets are replaced or repaired, these processes can be updated to capture this information in the TMS inventory. In turn, the inventory information can be leveraged to direct maintenance work plans and priorities.

INCORPORATING DOCUMENTATION PRACTICES INTO TMS MANAGEMENT AND OPERATIONS

Ongoing operations and management of TMS assets provide frequent opportunities for updating documentation of the TMS assets and incorporating them into a TMS inventory. When considering TMS lifecycle processes, this practice aligns with TMS monitoring, evaluating, and reporting, and allows for real-time asset condition and system monitoring to feed into the process of documenting TMS assets and resources, along with incorporating them into a TMS inventory. For example, each TMS software application may have different versions, customizable settings, and typical workflows. Agency staff who regularly use the software application are best suited to document specific information about the software, thereby enhancing the quality of asset documentation.

The continuous use of TMS assets requires each asset to be highly available, a priority for TMS maintenance and repair. Many TMS assets incorporate multiple technical components. The failure of one component can hinder capability of an entire TMS subsystem. By documenting ongoing performance over time, agencies can make informed decisions during the planning and development of strategic TMS plans, further strengthening their asset inventory. Operations staff often initiate maintenance efforts, such as creating maintenance tickets, which can have an impact on TMS resource allocation and administration. During these maintenance initiation efforts, the data entry process can be revised to reflect inventory documentation on the TMS assets in the maintenance report. For sustainability, agencies may consider automating the process of updating the inventory documentation, eliminating the need for any additional data entry steps.

As new technologies are procured and new projects are developed, new TMS assets are frequently added to an agency's TMS. Agencies may require contractors to submit final as-built plans including the new TMS asset information, such as location and installation date. This information can be documented in the TMS inventory. The final plan documents can also enrich the inventory, supporting the agency's future planning and feasibility studies.

Data management is a core strategy to support the management and operation of a TMS. This strategy can benefit from an integrated approach to documentation. Agencies may consider updating their TMS data management efforts to benefit their newly adopted inventory documentation processes. For example, an agency may have an ongoing monthly data management practice to review and improve TMS data quality. One step of this process might be to remove outlier or erroneous data.

The faulty data may have been generated for any number of reasons, such as:

- A TMS software module has a reporting bug.
- An operator of the TMS neglected to close a particular event, which generated the erroneous data point.
- A network glitch interrupted operations temporarily, causing the data issue.

No matter the cause, the monthly data quality assurance process exists to clean up such outliers before including bad data in performance reports. The agency may consider adding a step to ensure the cause of the data issue is appropriately documented and that all necessary data attributes are updated within the TMS inventory.

INCORPORATING CONFIGURATION MANAGEMENT PRACTICES INTO TMS MANAGEMENT AND OPERATIONS

Incorporating CM practices into TMS management and operations can enhance the system's effectiveness. As described in chapter 6, change control is a key CM process that allows an agency to assess the potential impact of any modification, large or small, on the entire system. Once a change has been approved, change control assists in proper administration and documentation of the change. This becomes especially important in managing TMS software updates, which are often grouped—sometimes as part of a release schedule—into routine updates. While existing protocols might immediately adopt the suggested changes into the next planned release, integrating change control brings an additional layer of accountability, ensuring that all configuration information remains current.

Other benefits of adding change control to update processes include:

- Change control enhances stakeholder communication by ensuring all stakeholders are informed about proposed changes.
- Change control requires an approval process where requests are formally prioritized before being approved.
- Change control allows agencies to identify and mitigate risks associated with changes before they are implemented.

Agencies may also benefit from developing a CM plan during any reviews or assessments of TMSs. Integrating results and recommendations from a TMS self-assessment into a CM plan can set the stage for a well-organized TMS.

When agencies are procuring new TMS assets, TMS improvements, or implementing a next-generation TMS, change management and CC processes can support vetting new technologies to align them with the existing systems. Any configuration history logs can also support any upgrades, as well as ongoing TMS monitoring and reporting. Tracking the lifecycle of an asset can also provide valuable data for audits and performance evaluations.

USING THE INFORMATION FOR TMS OPERATIONS

Once an agency has accumulated sufficient asset condition information, it can leverage the information to optimize TMS operations. As an example, when a TMS component malfunctions, an alarm could be activated, alerting maintenance staff to diagnose and resolve the issue. Access to historical data on downtime, condition, and device configuration can expedite this process. Informed by up-to-date asset condition data, agencies can implement routine TMS actions with confidence. Individual TMS actions often rely on several TMS elements functioning together. The action of changing a dynamic lane use control sign is an example.

This action might depend on multiple TMS elements working properly, including, but not limited to:

- Lane use control sign field devices.
- ITS network equipment.
- Operating procedures.
- TMS software modules.

If any one of these TMS elements is under repair or maintenance, this status would be readily available in the updated TMS inventory. Consequently, operations staff can make quick adjustments, such as opening a dynamic lane to support incident management. The function of an operator verifying a traffic incident is another example. The operating procedure may require the operator to verify the incident before disseminating traveler information updates.

The applicable verification methods may hypothetically include:

- Visual confirmation through CCTV.
- Visual confirmation from a service patrol operator or other first responder.
- Confirmation of traffic queues via traffic detectors.

When operators have real-time access to the status of TMS assets such as CCTV cameras or traffic detectors, incident verification becomes more efficient. If higher-priority or higher-tier assets are not functioning as intended, their statuses can have a direct, and often adverse, impact on operations and safety of travelers.

If asset information is incomplete, the agency may need to reevaluate its operational strategies or control plans, leading to slower response times for TMS actions. Another application of inventory information in TMS operations is network monitoring integration. Given the interconnected nature of many TMS elements, incorporating real-time and historical asset condition data into standard network monitoring processes can significantly benefit operations. This comprehensive asset information enables operations staff to quickly adapt to events. TMS asset managers, in turn, benefit from the added layer of detail provided by operations staff when inputting asset information into maintenance tickets.

IDENTIFYING AGENCY RESOURCES

A key step in implementing TMS practices in support of managing and using an inventory of TMS assets and resources could include identifying agency practitioners who contribute to day-to-day practices of establishing, managing, and using inventorying, documenting, and CM efforts.

Different personnel or support contractors within an agency can play various roles in these efforts:

- Staff responsible for diagnosing issues with TMS assets are key players in managing the assets and contribute insights to inventory and CM process or activity.
- Daily users of the TMS software can provide real-time feedback that aids documentation and system improvements.
- Staff overseeing TMS software testing and releases can ensure software updates are conducted smoothly, and results are well documented.
- Staff responsible for managing spare parts or replacement components can be involved in inventory practices to ensure resource availability for maintenance activities.
- Staff responsible for using asset performance history to generate and share reports are important for monitoring and reporting system performance measures.
- Resource managers for TMS activities can optimize staffing and budgeting based on the information available in the TMS inventory.
- IT staff managing TMS software, network, or data components can support CM processes.
- Contracted personnel may be inputting data as part of their ongoing responsibilities. Their insights can improve the completeness and accuracy of the TMS inventory.

The agency may also identify upcoming projects and initiatives that may impact TMS operations. These efforts provide opportunities for the incorporation these effective practices.

Examples of such projects include:

- Improvements to TMSs, operational strategies, or practices which may require changes to existing TMS assets or introducing new assets.
- New traffic incident management efforts that may require software changes, new operating procedures, or information to share.
- Improvement projects which may involve multiple TMS subsystems and components and need to be fully integrated into the TMS inventory.
- Nearby projects led by neighboring jurisdictions that have an impact on operations within the existing TMS coverage area.
- Large-scale freeway projects involving TMSs to manage and control traffic associated with a work zone which may involve the deployment and use of technologies, requiring expanding existing inventorying and documentation processes.

CHALLENGES TO CONSIDER

Incorporating inventorying, documenting, and CM practices into existing TMS operations is not without challenges. Operations staff who are used to real-time actions may find new procedural requirements to be resource-intensive and potentially at odds with the time-sensitive nature of their jobs.

When selecting data attributes to include in an inventory, the agency may consider balancing between:

- Collecting enough information to inform future decisions.
- Avoiding overwhelming staff by collecting too much information.

Understanding the role of specific documents in a TMS inventory can be a challenge. The documentation of field device manuals, for example, may appear redundant to some practitioners. Providing a more complete understanding of the TMS asset may remove some of the initial doubts of why specific documentation is being collected.

Introducing new processes and the accompanying changes to staff who manage assets can present a challenge, particularly early in the effort. Staff may be reticent, or even resistant, to being asked to change how they work—whether the changes involve what they do or how they do it. Effective communication and stakeholder involvement are key to overcoming these challenges.

Maintaining an updated TMS inventory over time may also be a challenge. An agency may consider being flexible with its processes to overcome this challenge. By accepting feedback and incorporating changes that align with the overall objectives, an agency can ensure its TMS inventory remains effective. This approach also demonstrates a willingness to adapt and improve, which can foster a positive and collaborative culture among staff.

Periodic review and evaluation of all TMS inventory processes can help identify areas for improvement and ensure the inventor's ongoing maintenance. Establishing a feedback loop is important in maintaining an effective TMS inventory. This can be achieved by sharing performance and maintenance statistics with operations and maintenance staff, setting maintenance schedules and priorities, and prioritizing funding for upgrades and replacements.

An agency can maintain positive momentum and ensure the TMS inventory is working effectively by acknowledging operations and maintenance staff contributions and communicating the realized benefits. This type of collaboration helps ensure the inventory is updated, accurate, and supports the overall objectives of the agency.

CHAPTER 8. INCORPORATING THE TMS INVENTORY INTO AGENCY PLANNING EFFORTS

This chapter describes what an agency can do to incorporate TMS asset inventorying and resources into other processes in the lifecycle of a TMS, a TMS plan, or TSMO program and plan, or other agency planning efforts. A well-maintained TMS inventory of assets and resources can be an important source of information that agencies can use in these different processes. Information from the TMS inventory can serve as key inputs that influence several agency processes and the development of strategic plans.

The objectives are to:

- Highlight the value of using the TMS inventory data to support agency planning efforts.
- Highlight the value of using documentation from the TMS inventory to enhance agency planning efforts.
- Provide examples of how TSMO planning processes can benefit from TMS inventory information.
- Explain how TMS inventory data can be used to support other agency or regional planning processes related to TSMO program or traffic management efforts.

This chapter includes the following sections:

- Incorporating Inventorying Practices into Agency Planning. This section introduces examples of planning efforts that may benefit from using TMS inventory information.
- Incorporating Documentation Practices into Agency Planning. This section emphasizes the role of asset documentation in support of enhancing agency planning processes.
- Incorporating Configuration Management Practices into Agency Planning. This section explores how integrating CM practices into agency planning processes may be beneficial.
- Leveraging TMS Asset Inventory Information. This section elaborates on how TMS asset information can be used for planning functions and interagency coordination efforts.
- Challenges to Consider. This section outlines potential challenges agencies may encounter when trying to integrate these processes into agency planning efforts.

INCORPORATING INVENTORYING PRACTICES INTO AGENCY PLANNING

Incorporating TMS asset information into agency planning processes is key for data-driven decisionmaking. While having an extensive TMS inventory is beneficial to managing and operating TMSs, it is also valuable when integrated this information into the applicable agency planning processes and efforts.

Example agency planning processes that may benefit from TMS inventory information include:

- TSMO plans.
- TAMPs.
- Active traffic and demand management plans.
- Smart corridor plans.
- Traffic signal optimization plans.
- Emergency response plans.
- Safety management plans.
- Transportation improvement plans.
- Freight mobility plans.
- Transit operations plans.
- Mobility-as-a-service (MaaS) plans.

In an agency TSMO plan, TMS inventory data serve as a foundation for decisionmaking and resource allocation. The inventory information offers insights into the availability, location, and condition of assets such as traffic signals, message signs, or traffic sensors. These data can help agencies identify operational gaps, prioritize improvements, and improve their TSMO program effectiveness. An agency's TAMP can leverage TMS inventory data to aid into agency asset management or other longer-term planning processes. The inventory data can provide insights into performance gaps, lifecycle costs, and historical asset information. These data can support agency TAMP efforts to plan for future improvements.

TMS inventory data can also support emergency response planning by offering a comprehensive view of asset information and capabilities. Knowing where traffic cameras, message boards, and key sensors are located helps in quick decisionmaking during emergencies. This asset information can be integrated into emergency plans to support the development of response strategies, communication plans, and real-time dissemination of situational awareness information.

For freight mobility plans, TMS inventory data can benefit agencies as they plan to improve the efficiency and safety of freight movement. The inventory may include details on the availability and location of weigh-in-motion systems, message boards along freight priority routes, and other key assets for freight movement. Using this information, planners can create strategies to reduce bottlenecks, improve freight safety, and optimize routes for freight carriers.

INCORPORATING DOCUMENTATION PRACTICES INTO AGENCY PLANNING

This section discusses the role of documentation to support agency planning. Much like TMS inventory data benefit an agency's planning processes, incorporating documentation practices can benefit an agency's decisionmaking. The same agency planning efforts discussed, such as TSMO and MaaS plans, can benefit from integrating comprehensive TMS documentation.

Documenting asset condition is an important part of an agency's TAMP. Agencies can consider incorporating documentation of their TMS assets into their preexisting TAMP efforts. In some cases, the agency's existing documentation efforts—as defined by the agency's TAMP efforts—may not be as complex or thorough as the documentation required for TMS assets. If possible, existing documentation processes may need to consider extra accommodations to incorporate additional information related to TMS assets.

For safety management plans, integrating TMS documentation can elevate the effectiveness of safety strategies. Comprehensive documentation can provide a historical record of asset performance, incident responses, and system adjustments. This information can help agencies understand safety trends, identify gaps, and optimize future countermeasures. Incorporating TMS documentation can allow for more robust data analysis, facilitating more informed safety measures.

For MaaS plans, the integrations of TMS documentation can enhance the service efficiency and user experience. MaaS usually involves multiple modes of transportation and real-time data usage. TMS documentation can provide insights into the availability, reliability, and performance of various traffic management assets contributing to the MaaS ecosystem. Documentation on aspects such as traffic flow trends, device reliability, and software updates can support fine-tuning MaaS offerings.

Documenting field device firmware updates can help an agency better plan future asset upgrades. Similarly, documenting software versions and configurations can help an agency better plan for future software updates. One example is a security vulnerability that impacts one specific firmware version or software version. If an agency maintains up-to-date documentation, it can quickly develop a plan to address the security vulnerability. Without up-to-date documentation, the agency would first have to update its inventory documentation before assembling an upgrade plan.

INCORPORATING CONFIGURATION MANAGEMENT INTO AGENCY PLANNING

CM practices can provide an additional layer of support to data-driven decisionmaking across various agency planning activities. By integrating CM, agencies can further refine and optimize their approach to planning for improved transportation management. CM practices can help manage changes to TMS assets, offering a more structured approach to maintaining, upgrading, and implementing new assets. These practices complement an agency's TAMP by ensuring asset data are always up to date, which supports long-term planning and resource allocation.

One output of CM efforts is reliable data that can be incorporated into TMS plans and processes. After establishing a CM program, agencies may begin documenting changes made to TMS assets and resources. This documentation may be incorporated into existing maintenance activities to ensure any changes to assets are automatically captured. To incorporate CM into agency planning efforts, the agency may consider starting with a CM plan. A CM plan establishes procedures to inform the entire CM effort.

A CM plan typically addresses:

- Agency staff who have an impact on CM.
- Administrative bodies.
- TMS assets under CM.
- CM policies, procedures, and activities.
- CM tool descriptions.

Before recommending new procedures, the CM plan can likely identify existing agency practices that may be incorporated into CM with minor tweaks. TMS programming, TMS resource allocation, and daily TMS operations are all processes where CM could be integrated. Additionally, TMS procurement projects would benefit from CM performed over the lifetime of each TMS asset.

With a complete historical record of asset configurations, the agency is better suited to:

- Assign routine maintenance schedules.
- Configure newly installed TMS assets properly.
- Prepare for a full asset replacement project.
- Create and present detailed reports on TMS asset performance.

By integrating CM practices into planning efforts, agencies can ensure that their TMS asset inventories remain accurate, up-to-date, and valuable for decisionmaking. This, in turn, supports the development of more effective plans, optimizes resource allocation, and ultimately improves the performance of their TMS.

LEVERAGING TMS ASSET INVENTORY INFORMATION

TMS asset information can support other specialized planning functions and interagency coordination efforts. For example, TMS asset inventory data can extend to contract and spare management. Inventory data can improve contractual relationships with vendors by reviewing historical performance and facilitating performance-based contracts.

Similarly, agencies can streamline spare management by leveraging inventory information for predictive and preventative maintenance. A unique characteristic of TMS assets is they often include swappable parts at the component and subcomponent levels. Agencies can manage spares using the TMS asset inventory, which may include considerations for inventorying spares and forecasting the need for spares. Leveraging spare parts information helps ensure assets meet their performance targets.

Agency decision makers may rely on TMS inventory data to define investment priorities in a few ways:

- Modifying preventive maintenance schedules and associated resources.
- Revising lifecycle cost assessments.
- Assessing the need for device upgrades, such as software and firmware.
- Informing asset investment planning.
- Assessing the comparative value of asset upgrade/repair versus replacement.

Periodic review and assessment of TMS inventory processes can help ensure the processes stay relevant and useful. Agencies can solicit feedback from planners to ensure the information remains relevant and actionable. This helps keep inventory processes in sync with planning needs.

An agency that has effectively integrated its TMS inventory into its planning processes can realize several benefits:

- Clearly defined policies aligned with planning needs.
- Improved understanding of effective configurations.
- Established feedback mechanisms to gather input from affected organizational entities.
- Adaptability to changing planning needs.
- Leadership who reinforces the value of inventory information.
- Use of the inventory information during procurement activities.

Asset investments often have ramifications beyond a single jurisdiction or agency. Coordinating across functional and jurisdictional boundaries can ensure inventory and documentation activities are consistent and beneficial for all parties.

Transportation systems are, by design, multijurisdictional. They are intended to facilitate mobility within, between, and through towns, counties, regions, and States. As such, TMS assets used to manage systems within one jurisdiction often affect mobility in surrounding jurisdictions. Although TMS assets are most often associated with roadway operations, they can impact other public sector and private sector transportation modes and facilities. It is important to coordinate TMS asset inventory and documentation activities with organizations that operate, manage, and maintain assets.

Partner agencies to consider coordinating with include:

- MPOs.
- Transit authorities.
- Neighboring DOTs.
- Neighboring municipalities.
- Toll/express lanes authorities.

CHALLENGES TO CONSIDER

The processes of inventorying, documenting, and CM may be perceived as bureaucratic, introducing unnecessary demands on financial resources and staff time. Clear communication, led by a designated champion, can help stakeholders understand the long-term benefits and ensure sustainability of these efforts. Operational staff, often involved in realtime tasks, can neglect routine procedures that sustain inventorying, documenting, or CM if the procedures are not integrated into their daily workflows. If routine processes do not incorporate steps to sustain inventorying, documenting, or CM efforts, staff may stop attending to them over time.

Creating an inventory framework that aligns with planning objectives can also be challenging. Understanding the planning timelines, expectations, and how the collected data will be leveraged are key considerations when establishing this connection. Setting well-defined expectations and goals for TMS assets and inventory management is important for successfully integrating inventory information into planning processes. This also establishes mechanisms for information reporting and sharing, as well as data collection that serves the needs of decision makers.

TMS practitioners may benefit from aligning TMS asset inventories with existing TAM processes. Similarly, TMS practitioners may benefit from aligning TMS CM efforts with existing CM processes—which may be led by the State IT agency, not the transportation agency. Each agency may consider assigning a champion to this effort. A champion can take the lead role of owning the process, communicating progress to different work units, identifying opportunities for improvement, and planning to sustain the efforts.

CHAPTER 9. MAINTAINING INVENTORY, CONFIGURATION, AND DOCUMENTATION QUALITY

This chapter provides insights into maintaining the quality of a TMS asset inventory, documentation, and configuration. It discusses the protocols for updating the inventory, the governance for approving changes, and safeguards to integrated modifications made during other processes. Emphasis is placed on the importance of updating documentation and completing verification before using the information.

The objectives are to:

- Summarize insights into managing a TMS inventory of assets and resources.
- Actions an agency may consider to update or develop a TMS inventory of assets and resources.
- Identify agency resources for managing and sustaining an inventory of TMS assets and resources.
- Identify potential challenges that may be obstacles in maintaining and updating a TMS inventory, ensuring long-term reliability.

The true value of a TMS asset and resource inventory can only be realized when the appropriate level of effort is applied to keep the information accurate, current, and complete. This requires that both the tools and the workforce engaged are equipped to handle the tasks effectively.

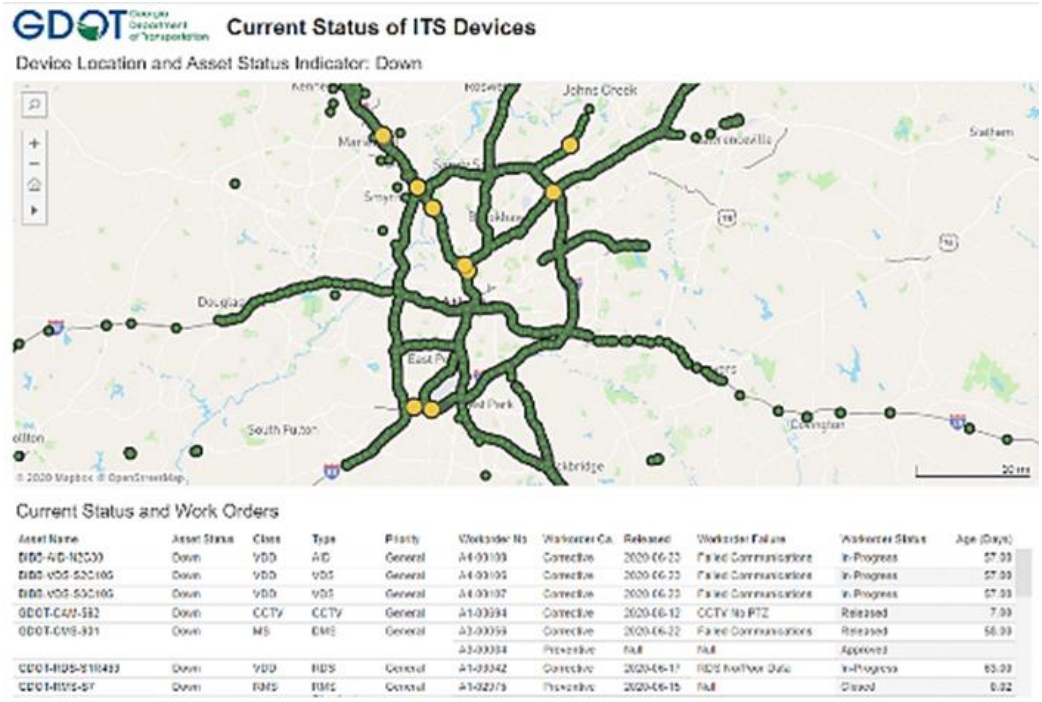
This chapter contains the following sections:

- Managing an Inventory. This section introduces practices an agency may consider to keep inventory information current.
- Maintaining Quality. This section discusses quality assurance practices an agency might adopt in support of the TMS inventory.
- Identifying Agency Resources. This section discusses the impact of maintaining a TMS inventory on agency staff.

MANAGING AN INVENTORY

Effective inventory management requires implementing appropriate controls and responsive update processes. This includes processing information updates as soon as possible. The complexity of keeping information updated often stems from the existence of multiple systems, restricted access for all stakeholders, and varying levels of experience and training in using the system. This section offers insight into effective practices to mitigate some of these complexities.

Planned TMS asset improvements involve either deploying new assets or upgrading existing assets. For example, new assets may be deployed as part of a larger construction project, or existing TMS assets may be upgraded as part of a TMS asset enhancement project. Additionally, existing assets may be improved via routine updates, such as software patches. Agencies can benefit from a dashboard interface to visually understand the current inventory and device configurations. As illustrated in figure 6, a well-designed dashboard can offer quick insights into asset names, types, and statuses, thereby assisting in effective inventory management.



© 2020 Georgia DOT. Original map © 2020 Mapbox © OpenStreetMap. Modified by Georgia DOT (see Acknowledgments section.) (Mapbox n.d.; OpenStreetMap n.d.).

Figure 6. Screenshot. Graphical depiction of documented asset information.

This dashboard function—linked directly to asset attributes, documentation, and configurations in the inventory—facilitates efficient and timely management actions. Regular inventory updates may work well as a regular step when repairing or replacing any asset or its components. These updates present opportunities to collect new or missing asset information.

By capturing information, agencies can benefit in multiple ways:

- Documenting a functional history.
- Facilitating action planning, prioritization, and sequencing.
- Recording service history, dates, and details.

Ensuring work orders contain all necessary asset information and instructing maintenance and other field staff to capture these data during routine actions allows for continuous updates to the inventory.

Other ways an agency can consider managing the TMS inventory include:

- User training: Regularly train the staff responsible for managing the inventory on how to properly document changes, handle software, and understand dashboard information.

- Documentation of procedures: Maintain a standard operating procedure manual for inventory management and keep it updated as processes evolve.

- Change management: Use a structured change management process for any updates or modifications, ensuring all changes are logged, reviewed, and approved by appropriate agency staff.

MAINTAINING QUALITY

A TMS inventory is more valuable if the data contained in it are accurate and free of errors. Maintaining data quality is a multifaceted approach encompassing data accuracy, governance, and system compatibility.

The following are some effective practices:

- Data quality assurance/quality control. This practice can be assigned to agency staff who are equipped with processes and tools. Data can be checked for accuracy and completeness at the point of capture and at the point of entry into the chosen data management tool.

- Data governance. This practice includes the mechanisms that control access to inventory data, as well as mechanisms that ensure data are properly stored and routinely backed up.

- Interface and database management. This practice ensures data interfaces adhere to industry-standard protocols for information security. Regular audits can be conducted to verify data integrity. Databases can be maintained with the latest configurations, licenses, and hardware to ensure compatibility and performance.

- Lifecycle monitoring. This practice is the concept of temporally tracking asset information to maintain data quality. These historical data inform future decisions on asset maintenance or replacement.

- CM processes. This practice includes processes such as CSA and configuration audits for key quality control.

- Policy alignment. This practice can extend existing policies and processes for data quality and secure access to TMS asset inventories.

- Data attributes and information access. This practice can be managed to continue providing a consistent set of information across all assets.

- Automated alerts. This practice can be implemented for outlier detection or discrepancies, ensuring a prompt response.

- Version control. This practice can help track changes of the inventory over time, allowing for easier rollback if necessary.

- Regular audits. This practice can identify issues or incomplete information of the information to help sustain data quality over time.

Using a combination of these practices can ensure TMS asset information quality over time. The next section considers balancing these efforts with the impact on agency resources.

IDENTIFYING AGENCY RESOURCES

One consideration for maintaining long-term quality of a TMS inventory is managing access to sensitive inventory data. For example, device maintenance staff may need read and write access to specific inventory data attributes to update the necessary information as repairs are being made. At the same time, TMS planners may only require read access to use the inventory information.

Roles that may be important for agencies to consider for varying levels of access to the TMS inventory include:

- TMC operators.
- ITS maintenance field technicians.
- IT program managers.
- IT database managers.
- TMS procurement staff.
- Data analysts.
- TMS planners.
- Contracted software developers.

The staff responsible for the TMS inventory processes may benefit from being equipped with information and tools, which includes:

- An understanding of the rationale for changes.
- Information about how these changes impact routine processes.
- Specifics of asset configuration modifications.
- Updated processes and procedures for implementing changes.
- Necessary inventory system updates, including user interface changes.
- Any required resources like funding, staff, and tools for execution.

As policies and procedures are formulated the agency may consider defining roles and responsibilities at the same time. Agencies could align these roles with the organizational components equipped to support them, such as human resources.

Roles supporting the CM process may include:

- CM manager who oversees the CM program.
- CM facilitator, typically a consultant with prior CM knowledge.
- CC board members.
- Technical experts.
- Project managers.
- IT staff.
- Document specialists.

APPENDIX. LITERATURE REVIEW

Table 7 lists the resources and references reviewed for this report.

Table 7. Resources and references.

Name	Source	Link
Transportation Asset Management Gap Analysis Tool	American Association of State Highway and Transportation Officials (AASHTO) 2014	https://www.tpm-portal.com/tool/tam-gap-analysis-tool-nchrp-08-90/
Integrating Asset Management Plans Into Transportation Planning Process: A Briefing Paper (report)	AASHTO 2015	https://www.tam-portal.com/wp-content/uploads/sites/12/2016/01/AM-Planning-Process.pdf
AASHTO Transportation Asset Management Guide: A Focus on Implementation. 2nd ed (report)	AASHTO 2022	https://www.transit.dot.gov/sites/fta.dot.gov/files/2022-03/AASHTO-Transportation-Asset-Management-Guide.pdf.
"AASHTO Transportation Asset Management (TAM) Portal" (website)	AASHTO n.d.	https://www.tam-portal.com/.
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
Asset/Fund Management Guidebook Technical Plan: ITS	Colorado DOT 2019	Not available
Review of Traffic Management Systems—Current Practice	FHWA, July 2023	https://highways.dot.gov/research/publications/operations/FHWA-HRT-23-051
"Strategies for Implementation." in *Asset Management Overview* (report)	FHWA 2007	https://www.fhwa.dot.gov/asset/if08008/amo_05.cfm
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

Name	Source	Link
Handbook for Including Ancillary Assets in Transportation Asset Management Programs	FHWA 2019a	https://www.fhwa.dot.gov/publications/research/infrastructure/19068/index.cfm
"Asset Management: Questions and Answers (Qs and As)" (website)	FHWA 2019b	https://www.fhwa.dot.gov/asset/guidance/faqs.cfm
"Completed Projects: TMC Performance Monitoring, Evaluation, and Reporting Handbook" (web page)	FHWA 2021	https://tmcpfs.ops.fhwa.dot.gov/projects/tmcpmerhdbk.htm
Applying Transportation Asset Management to Traffic Signals: A Primer	FHWA 2022a	https://ops.fhwa.dot.gov/publications/fhwahop20048/fhwahop20048.pdf
Applying Transportation Asset Management to Intelligent Transportation Systems: A Primer (report)	FHWA 2022b	https://ops.fhwa.dot.gov/publications/fhwahop20047/fhwahop20047.pdf
"Transportation Asset Management Expert Task Group: Resources" (web page)	FHWA 2023	https://www.fhwa.dot.gov/asset/etg/index.cfm
Asset Management for Operations (website)	FHWA 2024a	https://ops.fhwa.dot.gov/program_areas/ops-asset-mgmt.htm
"Automated Traffic Signal Performance Measures" (web page)	FHWA 2024b	https://ops.fhwa.dot.gov/arterial_mgmt/performance_measures.htm
"Transportation Asset Management Plans" (web page)	FHWA 2024c	https://www.fhwa.dot.gov/asset/plans.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
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
Major Equipment Life-Cycle Cost Analysis (final report)	Gransberg and O' Connor 2015	https://mdl.mndot.gov/items/201516
Elements of a Comprehensive Signals Asset Management System (final report)	Harrison et al. 2004	https://ops.fhwa.dot.gov/publications/fhwa_signal_system/
"Integrating Asset Management Into the Transportation Planning Process" (presentation)	Mercer 2016	http://onlinepubs.trb.org/onlinepubs/conferences/2016/AssetMgt/76.LauraMester.pdf

Name	Source	Link
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
Health Index and Performance Measurement for ITS (webinar).	NOCoE 2020c	https://www.youtube.com/watch?v=uxvQilg6NhQ.
"ATMS Infrastructure Alignment Project" (web page)	NOCoE 2022	https://transportationops.org/case-studies/atms-infrastructure-alignment-project
"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
Configuration Management for Transportation Management Systems Handbook (final report)	Smith 2003	https://ops.fhwa.dot.gov/freewaymgmt/publications/cm/handbook/toc.htm
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
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

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ACKNOWLEDGEMENTS

The *Current Status of ITS Devices* dashboard depicted in figure 6 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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Recommended citation: Federal Highway Administration, *Inventorying, Documenting, and Configuring Traffic Management System (TMS) Assets and Resources* (Washington, DC: 2024) https://doi.org/10.21949/1521542

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