Managing Traffic Management Systems Assets

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6300 Georgetown Pike
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<tr><td colspan="4">16. Abstract
A traffic management system (TMS) is composed of a complex, integrated blend of hardware, software, and people performing a range of functions and actions. TMS assets are the physical elements of a TMS that support the reliable operation of the TMS, including the hardware, software, infrastructure, or equipment required by a TMS, such as cabinets, foundations, and poles. This report describes activities and resources an agency may use in support of managing TMS assets to maintain and improve these assets’ performance and lifespans. The report discusses TMS asset identification, classification, and inventorying; key aspects of managing and maintaining TMS asset data; managing TMS asset spares and replacements; TMS asset configuration management; and TMS asset monitoring, evaluation, and reporting. While the report focuses on managing TMS assets, it also identifies how the related activities and results support transportation asset management (TAM) for TMSs. In the report, the activities are linked to the elements of an agency’s TAM program and activities.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ATMS	advanced traffic management system
Caltrans	California Department of Transportation
CCTV	closed-circuit television
CFR	Code of Federal Regulations
CSA	Configuration Status Accounting
CMS	changeable message sign
COTS	commercial off the shelf
DOT	Department of Transportation
FHWA	Federal Highway Administration
GIS	geographic information system
GPS	Global Positioning System
HAR	Highway Advisory Radio
IAMS	Intelligent Transportation Systems (ITS) Asset Management System
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
IT	information technology
ITS	intelligent transportation systems
KITO	Kansas Information Technology Office
LCCA	lifecycle cost analysis
MAP-21	Moving Ahead for Progress in the 21st Century Act of 2012
MTTF	Mean Time to Failure
NHS	National Highway System
QR	quick response
RAMC	Reliability, Availability, Maintainability, and Capability
ROADS	Reliable, Organized, Accurate, Data Sharing
SE	systems engineering
TAM	transportation asset management
TAMP	Transportation Asset Management Plan
TMC	Transportation Management Center
TMS	traffic management system
TSMO	Transportation Systems Management and Operations
U.S.C.	U.S. Code

CHAPTER 1. INTRODUCTION

OVERVIEW

As defined in the *Review of Current Traffic Management Systems (TMS) Practices* report, a TMS comprises a complex, integrated blend of hardware, software, processes, and people performing a range of functions, services, and actions.(1) TMSs focus on improving the efficiency, safety, and predictability of travel on the surface transportation network. TMSs combine field equipment, operations personnel, and advanced communications and information technology (IT) to meet their missions. TMSs rely on technologies, software and software applications, services, and transportation data to manage and support roadway operations, maintenance, planning, and design.

Agencies are adjusting to the evolution of TMSs that incorporate and rely on new data sources, data subsystems, emerging technologies and require proactive management and operation. 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. The practice of inventorying all TMS devices and recording critical information, such as location, installation date, age, and condition, with the purpose of monitoring device condition for periodic maintenance and eventual replacement, is referred to as transportation asset management (TAM) for TMS.

TAM for roadway infrastructure, such as pavement, bridges, and other roadside infrastructure elements, has been in practice for a number of yr. TMSs contain assets that are relied upon to meet agencies' mission and performance objectives. As transportation agencies expand the use of and investment in TMSs, agencies may benefit from consistently and effectively managing TMS assets. Benefits 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.

While agencies typically have TAM programs to manage roadway infrastructure assets, limited information is available on how to manage TMS assets. Interviews with State agencies reveal that managing TMS assets is typically done in a less formal and less programmatic manner than for other traditional transportation assets. The activities cited by agencies were often born from necessity and developed ad hoc. These ad hoc activities maybe in part due to a lack of information on what practices to consider in support of managing TMS assets.

Within many agencies, TMS data are collected by diverse groups, such as the staff of a transportation management center (TMC) or a maintenance group, who each use the information for unique purposes. The result has often been agencies addressing immediate needs for their TMSs without developing more comprehensive and consistent plans to support TMS projects, needed improvements, or the next generation of TMS.

The purpose of this report is to describe the activities, practices, and resources agencies may consider as they seek to improve managing their TMS assets.

REPORT OBJECTIVES

This report describes a structure of possible activities, tools, and resources for managing TMS assets given their unique characteristics. Central to this structure is TMS asset data that agencies can collect to define the assets, determine their conditions and needs, support their upkeep, and report asset information to other transportation stakeholders. While the activities and practices in this report may seem complex, they often align with existing agency efforts. Readers of this report are encouraged to relate how their existing activities may be adapted to support effective managing of their TMS assets.

The report objectives are as follows:

- Demonstrate the value of managing TMS assets.
- Define a framework of the activities, tools, concepts, and resources for managing TMS assets.
- Illustrate how managing TMS assets aligns with TMS activities, processes, and plans.
- Demonstrate how different types of data can be used to manage TMS assets.
- Provide examples of activities and practices to manage TMS assets.

INTENDED AUDIENCE

Managing TMS assets is intended to benefit practitioners who manage TMSs and rely on these assets to perform as necessary. These practitioners may include TMC managers and supervisors, transportation engineers and planners, maintenance personnel, researchers, and others having a role in transportation system management, operations, and maintenance.

The intended audience includes representatives from State departments of transportation (DOTs), local agencies, metropolitan planning organizations, regional authorities, toll authorities, or other groups involved with or who support TMSs. In addition, consultants, contractors, and researchers working with TMSs or supporting agencies operating TMSs will benefit from reading this report.

In developing this report, the research team conducted interviews with individuals active in operating, maintaining, and managing TMSs. The interviews identified information on topics of particular interest to the intended audience and which were incorporated into this report. In addition, the interviewees discussed and provided examples of practices that benefited agencies' efforts to manage TMS assets. Those examples are included in this report.

TMS

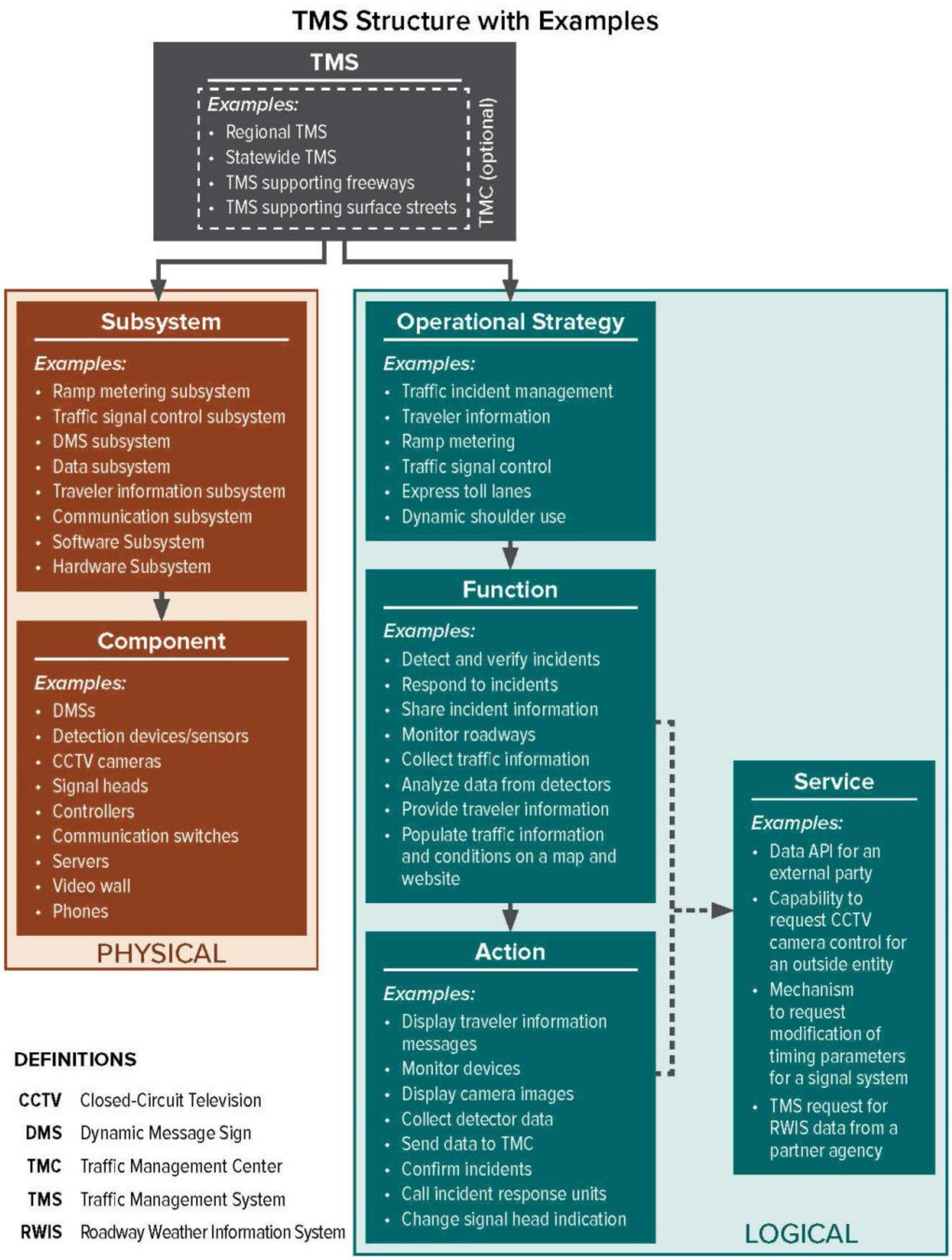
A TMS comprises a complex, integrated blend of hardware, software, processes, and people performing a range of functions and actions. The TMS assets are the physical elements of a TMS that can be managed. These elements may include the subsystems, components, devices, support resources, and other items an agency identifies as being needed to manage and operate a TMS.

Agencies may also include infrastructure a TMS needs, such as cabinets, foundations, and poles. Agencies should consider managing assets for both physical and logical elements of a TMS.

Agency's TMSs are typically composed of multiple subsystems, each of which supports one or more of the agency's operational strategies. Figure 1 illustrates the general structure of a TMS showing examples of both the physical and logical elements and the associated operational strategies. The figure is not comprehensive; agencies may have other examples of subsystems, components, operational strategies, functions, actions, and services that their TMSs support, but which are not shown. Also, an agency may not operate or have all the subsystems, components, or operational capabilities (e.g., services, functions) shown in this figure.

Components are devices or hardware elements that serve a purpose within a larger subsystem or TMS. For example, a changeable message sign (CMS) subsystem may include the individual devices located along the roadway, such as CMSs, concrete bases, poles, electrical or solar service, and communication media to share information with the TMS. For a ramp metering subsystem, the components may comprise the ramp meter algorithm and software, traffic controller, detection equipment (e.g., loops), electrical service, and communication media to share information with the TMS at each equipped on-ramp.

Not shown in figure 1 are the discrete elements or devices that a component may be composed of. For example, a CMS component may include network communication hardware, the CMS mount, electrical service, the sign board, computer hardware, and software.



Source: Federal Highway Administration (FHWA).

Figure 1. Diagram. Examples of TMSs physical and logical elements.[(1)]

This report discusses the activities, resources, and tools for managing TMS assets and defines the resulting benefits and expectations. Managing TMS assets addresses the following questions:

- Which TMS assets will be managed?
- What information is needed to manage the TMS assets?

- What existing resources, tools, and activities support or rely on managing TMS assets?
- How does an agency use and manage TMS asset information?

Agencies should understand that TMS assets are unique from traditional transportation assets such as pavement and bridges. TMS components, devices, and elements are complex and may have unique aspects and technologies. Characteristics of TMS assets include the following:

- **Technology elements—**Assets can require specialized skills, equipment, and materials to maintain them. Managing these assets using an approach similar to IT asset management may be more effective than the approach for managing traditional transportation assets.

- **Monitoring**—Assets that rely on technology can fail without warning or signs of degradation and may require constant monitoring to assure their performance. Agencies should have established performance targets for the availability of TMS assets that require frequent monitoring for verification.

- **Functional obsolescence**—An asset can become obsolete due to changes to standards, outdated software, a lack of spare parts, and changes in other systems with which the asset interacts.

- **Fungibility**—An asset may be maintained through the replacement of its components or devices, which may alter its configuration, functionality, and performance.

- **Portability—**Assets such as work zone equipment and portable signs can be moved and may not have a fixed location, presenting the potential for assets to get lost if not tracked properly.

- **Communications—**Assets are typically IT and rely on communications networks to exchange that information. As such, the performance and reliability of a TMS asset may be impacted by communications issues beyond an agency's control.

- **Degradation**—Assets typically do not degrade in the same manner as roadway infrastructure assets, which typically degrade gradually over time through wear and environmental conditions. The condition of some TMS assets is binary: operational or not operational.

As a result of their characteristics, TMS assets may benefit from unique approaches to how each type of asset is managed. Each agency also has planned and deployed a unique set of TMS assets that address the agency's operational needs. Those needs may include:

- Creating awareness of and responding to traffic flow disruptions.
- Reporting on and measurement of transportation network performance.
- Managing the use of operational strategies in response to changing conditions.
- Disseminating traveler information.

TAM

Agencies use TAM to manage transportation infrastructure with improved decisionmaking for resource allocation. TAM processes help agencies identify programs/projects on which to spend/invest their funding for the best long-term benefit.

Federal legislation, including the *Intermodal Surface Transportation Efficiency Act of 1991* (ISTEA) and the *Moving Ahead for Progress in the 21st Century Act of 2012* (MAP-21), has codified asset management principles.(2,3) ISTEA first established the use of management systems for roads, bridges, and other transportation assets. More recently, MAP-21 required all State DOTs to develop risk-based transportation asset management plans (TAMP), a requirement that is continued in the *Infrastructure Investment and Jobs Act*.(4) The FHWA has implemented the asset management requirements of 23 U.S. Code 119 by promulgating the asset management rule at 23 Code of Federal Regulations (CFR) part 515.(5) The definition of TAM in 23 CFR § 515.5 is:

> *A strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on 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.*

Further, 23 CFR 515.7(a) requires State DOTs to develop a TAMP that describes how the agency will manage its roads within the National Highway System (NHS) to achieve system performance effectiveness and an agencies' targets for asset condition while managing risk in a financially responsible manner and at a minimum practicable cost over the lifecycle of an agencies' assets. FHWA has developed resources to help transportation agencies prepare and use a TAMP.

State DOT TAMPs are required to address eight key elements for NHS pavements and bridges. Although encouraged, no requirements exist for addressing TMSs in a TAMP. If a State elects to include other NHS infrastructure assets or other public roads assets in its asset management plan, 23 CFR 515.9(l) describes the minimum information to be included and states that the level of effort used should be consistent with the State DOT's needs and resources.

The elements required for NHS pavements and bridges, however, provide guidance for asset management approaches for other assets. The following eight elements, extrapolated from 23 CFR part 515, can also be applied to TMS:(5)

- **Summary listing of assets (23 CFR 515.9(b)-(c) and (d)(3))**—A summary of assets, including a description of the asset condition.

- **Lifecycle planning (23 CFR 515.7(b))**—A process to estimate the cost of managing an asset class or asset subgroup over its lifespan, with consideration for minimizing cost while preserving or improving the asset's condition.

- **Asset management objectives (23 CFR 515.9(d)(1))**—Objectives that are aligned to the agency's mission and designed to achieve and sustain the desired state of good repair over the lifecycle of the agency's assets at a minimum practicable cost.

- **Measures and targets for asset condition (23 CFR 515.9(d)(2))**—Asset management measures and asset condition targets that are aligned with the agency's asset management objectives. These parameters could include measurements and associated targets to assess the performance of the highway system as it relates to those assets.

- **Risk management (23 CFR 515.7(c))**—A process and framework for managing potential risks, including identifying, analyzing, evaluating, and addressing the risks to assets and system performance.

- **Performance gap identification (23 CFR 515.7(a) and 515.9(d)(4))**—Gaps between the current asset condition and agency targets for asset condition and the gaps in system performance effectiveness that are best addressed by improving physical assets.

- **Financial planning (23 CFR 515.7(d) and 515.9(d)(7))**—A long-term plan spanning 10 or more yr, presenting the agency's estimates of projected available financial resources and predicted expenditures in the asset category to support achievement of the desired state of good repair.

- **Investment strategies (23 CFR 515.7(e), 515.9(d)(8), and 515.9(f))**—A set of strategies that result from evaluating various levels of funding to support achievement of the desired state of good repair at a minimum practicable cost while managing risks.

MANAGING TMS ASSETS

While States are developing TAMPs that address roadway and bridge assets, only a few States (currently California, Minnesota, Nevada, and Utah) have added or included TMSs or intelligent transportation system (ITS) devices into their TAMPs. Other States may have not incorporated TMS assets into TAMPS for several reasons, including a lack of resources to assess conditions, lack of off-the-shelf asset management tools that support the complexity of TMS assets, and limited information on the benefits of managing TMSs and integrating this information into a TAMP.

While asset management has a broad focus on the value of assets to an organization and on long-term outcomes, managing specific assets has a narrower focus. Managing TMS assets may involve the monitoring, management, evaluation, and maintenance that may be needed to ensure they meet the TMS and agency expectations. While asset management requires periodic assessment, managing specific assets typically may include daily activities such as maintenance and monitoring.(6)

The following information summarizes key differences in focus between asset management and managing assets.

Managing assets focuses on:

- Supporting availability, reliability, and dependability through asset care.
- Managing data that defines the assets, such as make and model, locations, quantities, and conditions.
- Understanding maintenance needs.
- Monitoring and measuring asset performance.
- Identifying resources and tools to support managing assets.

Asset management focuses on:

- Identifying how assets address agency objectives.
- Predicting and planning for long-term outcomes.
- Measuring how assets contribute to agency value.

This report addresses managing TMS assets and describes a structured approach to the activities and resources that support managing TMS assets. However, note that managing and operating TMS assets creates valuable information that also supports TMS asset management. The report identifies the connection between managing TMS assets and the eight elements from 23 CFR part 515 that can be applied to TMSs, as summarized in table 1.

Table 1. Managing TMS asset themes and related TAM plan elements.

Managing TMS Assets Themes	TAMP Elements
Identifying, classifying, and inventorying TMS assets	Summary listing of assets Lifecycle planning
Managing and maintaining TMS asset data	Summary listing of assets Lifecycle planning Asset management objectives Measures and targets for asset condition Performance gap identification
Monitoring, evaluating and reporting on TMS assets	Measures and targets for asset condition Performance gap identification

TRANSPORTATION SYSTEMS MANAGEMENT AND OPERATIONS (TSMO) AND MANAGING TMS ASSETS

TSMO is defined in 23 U.S.C. 101(a)(30)(A) as:

> *[I]ntegrated strategies to optimize the performance of existing infrastructure through the implementation of multimodal and intermodal, cross-jurisdictional systems, services, and projects designed to preserve capacity and improve security, safety, and reliability of the transportation system.*[7]

The goal of TSMO is to maintain and, where possible, restore the performance of the existing system before it needs extra capacity, usually by using TMSs. TSMO also helps agencies balance supply and demand and provide flexible solutions to match changing conditions. An effective TSMO program enables agencies to target underlying operational causes of congestion and unreliable travel through innovative solutions that typically cost less and are quicker to implement than adding capacity.

TSMO relies on TMS assets, and an agencies' TSMO program can provide the resources needed to manage and operate a TMS, manage TMS assets, and for other services and functions that are associated with achieving the objectives of the TMSO program.

Potential connections between a TSMO program and managing TMS assets include the following:

- **Strategic connections—**Includes incorporating functional and performance objectives and priorities for services and functions for TMS assets into the agencies TSMO strategic or program plans. The performance targets established by TSMO can be most efficiently achieved through managing the TMS assets.

- **Programmatic connections—**May include incorporating staffing, standard operating procedures, and resources for maintaining and operating a TMS into the agency's TSMO program plan and budgets. Agencies that plan for and provide the resources to manage their TMS assets may find cost benefits from prolonged TMS asset lifespans and more reliable functionality of their TMS assets. In addition, managing TMS assets may result in more complete and more accurate information for TSMO program decisionmaking.

- **Tactical connections—**Includes improving the activities for managing TMS and incorporating the needed resources into the TMS or TSMO program plan. Agencies used these connections in support of obtaining the needed financial resources or including the consideration of resources for managing assets into the planning for TMS improvements.

Agencies are recognizing the importance of managing their TMS assets in their overall TSMO programs, as illustrated in the following examples:

- Minnesota DOT has a TSMO-driven focus for managing TMS assets. It identifies three goals in their TSMO strategic plan, one of which is to "carefully and responsibly manage transportation operation assets."[8]

- Ohio DOT's TSMO plan includes asset management among the 21 TSMO functions in a data-driven approach to managing the transportation system.(9)
- Oregon DOT identifies asset management as one of its TSMO Program Areas.(10)

BENEFITS OF MANAGING TMS ASSETS

The benefits an agency may experience by managing TMS assets include the following:

- Monitoring, managing, and reporting on TMS assets' condition.
- Achieving and sustaining a desired performance (e.g., state of good repair) for managed TMS assets.
- Managing TMS assets' lifecycle to achieve desired performance with lower overall costs.
- Improving the performance of TMS assets and, as a result, the overall TMS.
- Integrating the condition of TMS assets and resources into how they are managed, maintained, repaired, replaced, and operated.

In summary, managing TMS assets supports an agency understanding its inventory of assets, their condition and performance, and what to expect from them in the future. This understanding helps an agency in operating and planning for TMSs and optimizing agency investment, which can result in improved return on investment and potentially justify expanding the use of TMS to address agency objectives.

Each agency's approach to managing TMS assets may be customized to its needs by creating a strategy that considers priorities and performance objectives. Agencies may use the data they collect and analyze when managing TMS assets to identify decision points and actions that will benefit their TMS assets.

REPORT ORGANIZATION

This report has 10 chapters, organized as follows:

- **Chapter 1. Introduction**. This chapter introduces the report and its purpose, defines TMS and the concept of managing TMS assets, summarizes the relationship between TAM and managing TMS assets, and describes the benefits of managing TMS assets.
- **Chapter 2. Applying TAM to TMSs.** This chapter provides an overview of the activities, practices, and resources to consider when applying TAM to managing TMS assets.
- **Chapter 3. TMS Asset Identification and Classification.** This chapter discusses the considerations, activities, and practices for identifying the TMS assets to be managed and establishment of a classification structure that supports TMS asset management. Asset

identification and classification defines what an agency will manage and for which assets it will have inventory information.

- **Chapter 4. TMS Asset Inventory.** This chapter discusses the information an agency may collect on TMS assets to understand what is being managed and the attributes of the assets that help understand their condition, performance, and needs. The inventory defines the types of data needed to understand the assets.
- **Chapter 5. TMS Asset Data Management.** This chapter discusses the key aspects of collecting, storing, maintaining, and sharing TMS asset data, including considerations for ensuring data quality and availability and the tools and resources available to help manage the data.
- **Chapter 6. TMS Asset Condition.** This chapter discusses the value of understanding assets' condition and the activities, practices, and resources for defining and determining condition from the asset data.
- **Chapter 7. TMS Asset Data Maintenance.** This chapter provides an overview of the purpose of maintaining TMS asset data, including data for asset costs over their lifecycle and the activities, practices, and resources for performing asset data maintenance.
- **Chapter 8. TMS Asset Spares and Support Resources.** This chapter discusses the role of spare management in managing TMS assets, including the activities, practices, and resources for estimating appropriate spares inventory, forecasting spares needs, and spares allocation and tracking.
- **Chapter 9. TMS Asset and Resource Configuration**. This chapter describes the relationship and synergies between asset management and configuration management and how managing TMS assets provides opportunities and data for configuration management.
- **Chapter 10. Monitoring, Evaluating, and Reporting on TMS Assets**. This chapter provides information on how managing TMS assets may provide information and context that can be used to monitor, evaluate, and report on TMS in support of an agency's TMS processes and planning.

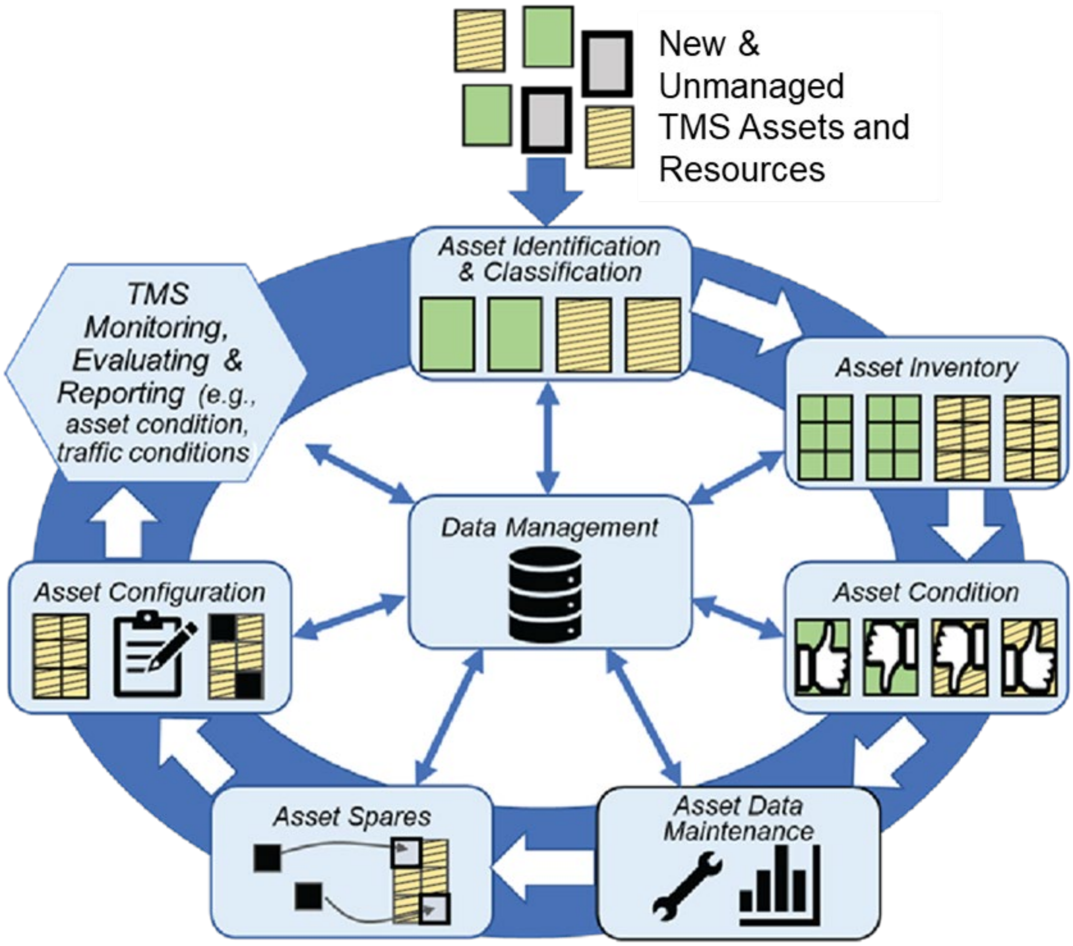
CHAPTER 2. ACTIVITIES AND RESOURCES FOR MANAGING TMS ASSETS

OVERVIEW

The purpose of this chapter is to provide an overview of the activities, resources, and relationship between TAM, managing TMS assets, and how information on TMS assets may be incorporated into other processes that influence the lifecycle of a TMS. This chapter focuses on providing a high-level understanding of these activities and their relationships to each other and providing the reader with a foundational understanding that supports the more detailed discussion in subsequent chapters.

This chapter details how managing TMS assets provides the benefits discussed in chapter 1 and supports TMS strategic planning, planning for improvements, and programming processes (e.g., TSMO, agency) within an agency. Accordingly, the chapter describes what an agency may consider in support of managing TMS assets and summarizes content that is described in more detail in later chapters.

Figure 2 illustrates a series of activities to consider in support of managing TMS assets as described in this chapter.



Source: FHWA.

Figure 2. Diagram. Managing TMS assets activities.

PREPARING TO MANAGE TMS ASSETS

This section illustrates the value of understanding current activities, available information, and agency stakeholder needs by describing various existing agency activities and how each may support efforts to manage TMS assets. Awareness of what an agency currently has available and what is already being done for TMS assets may help an agency to understand what additional activities, practices, and resources could be initiated to further the management of TMS assets.

The following subsections discuss activities that agencies may consider for enhancing how they manage TMS assets. The authors describe typical resources and existing activities that an agency may already have available and use. Information is also provided on how an agency might leverage these activities to support enhancing efforts for managing TMS assets or expand these existing practices to encompass specific TMS assets. Examples of existing experiences and relationships, which are described in more detail later in this chapter, include the following:

- An agency may already manage some TMS assets, either informally or as part of broader efforts to manage other transportation assets.

- Tools and experiences used to manage other transportation assets may also support the management of TMS assets.

- Existing relationships among stakeholders may provide a basis to engage others in planning to manage TMS assets and support a collaborative understanding of activities underway to manage TMS assets. Identifying what resources may be needed, what options are available to attain them, what issues may exist, and how to secure funding can also be helpful.

Existing Experiences with Managing TMS Assets

Agencies utilize staff resources and tools for collecting data, analyzing data, and managing, and reporting on the condition of a wide range of transportation assets, including ITS and TSMO assets. TMS assets may already be managed within these efforts, which may then be leveraged for managing other TMS assets. For example, some States report on TMS assets as part of broader efforts to manage their transportation assets. Identifying these existing experiences with agency stakeholders will facilitate planning efforts for managing TMS assets in a way that aligns with these activities.

Less formal activities for managing TMS assets may include the collection of records and documentation regarding specific TMS assets by agencies without formal business processes to ensure consistent data collection, inventorying, access, or sharing. The records and informal efforts may provide a starting point to formalize the management of TMS assets and help agencies identify what TMS assets will benefit from being managed, as described in more detail in chapter 3.

Expanding on existing experiences and informal management of TMS assets may involve asking the following questions:

- What TMS assets are currently managed as part of the agency's existing asset management process, or what additional assets may be appropriate to also manage?

- What activities are in place to document asset condition (e.g., an inventory of supporting information)?

- How is the performance of TMS assets documented and used?

- What costs does the agency incur managing TMS assets?

- What existing activities, resources, and tools exist for collecting, managing, and sharing TMS asset information, including items that may be part of other TAM efforts?

- What additional information and resources does the agency need to initiate or expand efforts to manage TMS assets, and what is needed to help prioritize which TMS assets to manage in a way that incrementally advances these efforts?

For many agencies, existing activities may closely relate and overlap with many of the activities described in this report, particularly data management and planning efforts. Readers may view figure 2 and map their current activities to those shown.

Existing Relationships Among Agency Stakeholders to Support Managing TMS Assets

Managing TMS assets can benefit from many different activities within an agency. A variety of relationships and activities that provide a basis for engaging others to plan the managing or improve how an agency may be managing TMS assets may already exist within an agency. Collectively, agency practitioners who support a variety of agency functions will benefit from collaboration when developing an incremental strategy to expand existing efforts or creating a new initiative to manage TMS assets.

Similarly, individuals responsible for managing TMS assets in an agency may benefit from relationships with other groups in the agency to leverage resources and information available from those groups' efforts to manage TMS assets. Overall, collaboration will help all stakeholders understand the activities already underway to manage TMS assets, what activities may be needed, what options are available, and what issues may exist. This understanding can be used to effectively build on what an agency already does. Collaboration and mutual understanding will help an agency to initiate or expand managing TMS assets in an efficient and cost-effective manner.

Further, as an agency works to initiate or expand efforts to manage TMS assets, communicating the benefits and value of managing TMS assets will be important to generate support and momentum for initiating or expanding the effort. By informing decisionmakers and managers, the agency will support the appropriate allocation of funding and staff resources. Discussions with field staff can help identify concerns, ideas, and feedback for managing TMS assets.

Expanding on existing relationships to support managing TMS assets may involve asking the following questions:

- Why is the agency starting or expanding an effort to manage TMS assets now? What activities should the agency conduct? What information might the agency need? How can the agency use that information?
- What other stakeholders, in addition to existing relationships, should be involved in defining the effort for managing TMS assets? In other words, what other stakeholders may be able to use TMS asset information or have access to data and tools that could support this effort?
- What degree of engagement should each identified stakeholder participate in these efforts?

IDENTIFYING, CLASSIFYING, AND INVENTORYING TMS ASSETS

This section describes the activities and resources to consider in support of managing TMS asset identification, classification, and inventory. with additional information provided in the chapters that follow. First, this section covers identifying the TMS assets that an agency may manage.

Second is a discussion of how agencies may determine the information that has value in defining and understanding the assets. The third section covers data management, which is core to managing TMS assets by ensuring that quality data are collected, stored, managed, and made available for analyzing the assets' condition, performance and considering possible future needs or activities (e.g., maintenance, repair).

TMS Asset Identification and Classification

After an agency establishes its need to manage TMS assets and the objectives of managing these assets, a key activity is identifying which TMS assets to manage. The identification process includes determining whether managing an asset is valuable and feasible and what improvements can be expected through managing the asset.

After identification, assets should be classified in a manner that supports the agency's TMS management. During the classification process, agencies may group assets in a number of ways, including the following:

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

The result for each agency is a classification structure that supports understanding the condition, performance, and needs of the assets.

TMS Asset Inventory

Key to understanding the identified and classified assets is defining them with inventory information, as discussed in chapter 4, TMS Asset Inventory. The chapter describes what may comprise TMS asset inventory, the attributes that may be used to describe TMS assets, cost, and life attributes of TMS assets, and challenges in collecting asset inventory data. This information may include static data points such as an asset's make and model, installation, and classification. It will also include dynamic 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 and then determine how to manage the asset.

MANAGING AND MAINTAINING TMS ASSET DATA

This section describes the range of potential activities, tools, and resources for maintaining TMS asset data for the assets that have been identified, classified, and inventoried. As illustrated in figure 2, data management is at the core of managing TMS assets and relies on the accurate collection, storage, and accessing of the data to support other TMS management activities. Data management is based on continual and systematic updating of information that creates a history on the TMS assets that helps define their status and any changes over time. This includes tracking information on the maintenance performed on a device, use of spare parts, or repairs conducted to assets that have failed or may be expected to require maintenance to prevent failures. Another key aspect of data management is configuration management on the assets, meaning how they have changed over time, and how changes may impact their condition, functionality, and performance.

TMS Asset Data Management

Figure 2 highlights the importance of data management while managing TMS assets and is the focus of chapter 5, TMS Asset Data Management. As Figure depicts, data management impacts all other activities needed to manage TMS assets. A key action for managing TMS assets is identifying the data that may be available from a variety of sources, such as advanced traffic management systems (ATMS), geographic information systems (GIS), and maintenance management systems, and mapping these available sources of data to what may be needed for managing specific TMS assets. As discussed in data management in chapter 5, agencies benefit from centralizing data, or at least understanding where data are located so they are not redundantly collected and stored. Centralizing the archive of accessible data provides a sole source of "data truth."

Agencies already have information on their TMS assets. However, they do not always manage it in a consistent, useful, or accessible way. For example, individual agency staff retain documentation or record activities regarding specific TMS assets for their individual purposes, but the information is not shared and may overlap with data collected by others for different purposes. These informal efforts may provide a starting point to initiate or formalize TMS asset management activities. The data may provide sufficient historical information that supports other activities or analysis to be conducted with managing TMS assets.

Likewise, agencies may employ informal approaches to identifying what TMS assets to manage. Current data collection efforts may serve as a foundation around which to develop more formal data governance structures (i.e., to ensure that data are consistent, quality-controlled, secured, and accessible) and expand data collection.

Quality data are central to effectively managing TMS assets. Data management includes consideration of data principles, data curation, data quality, systems engineering (SE) and documentation, data access and sharing, and data tools, all of which are discussed in chapter 5, TMSs Asset Data Management. Many agencies already utilize extensive software or programs to query data and generate reports for a variety of transportation assets as part of existing management efforts. Agencies may be able to leverage these systems and expand their capabilities to incorporate TMS assets. Likewise, policies and procedures for ensuring data quality and secure data access may be leveraged for managing TMS assets.

TMS Asset Condition

Agencies often struggle to understand how to accurately forecast the needs of their assets. Accurate information on the condition of assets helps an agency to establish expectations for its TMS assets, such as the level of performance, useful remaining life, and present value to the agency. Chapter 6, TMS Asset Condition and Lifecycle, discusses how agencies may assess the condition of their TMS assets and how data supports accurate condition assessment of specific assets. For many agencies, an asset's condition is related to its lifecycle. Strategies for assessing assets in a TMSs lifecycle are also discussed in this chapter.

TMS Asset Data Maintenance

Chapter 7, TMS Asset Data Maintenance, discusses the value of managing, maintaining, and governing TMS asset data. Governance includes the policies, procedures, and actions supporting the systematic updating of information on assets. Governance provides insight into an agency's inventory and how it has changed, which helps inform the approach to maintaining and operating TMS assets going forward. Agencies likely have a variety of data management policies, procedures, and practices that are used for other TAM efforts, TSMO, or TMS programs. These efforts provide a great starting point for managing TMS asset data, rather than starting from scratch, and any effort to manage TMS assets should align with these existing data management approaches.

TMS Maintenance and Use of Asset Spares and Resources

A unique characteristic of TMS assets is that they may be composed of swappable parts at the component or device levels. Swapping parts may allow agencies to repair a nonoperational asset or keep an asset operating and performing as required. The fungibility of TMS assets may justify keeping a stock of spares. Chapter 8, TMS Asset Spares and Support Resources, discusses the management of spares and the resources that may be used, including considerations for inventorying and forecasting spares that may be needed as replacements to ensure assets meet their performance targets.

TMS Asset and Resource Configuration

Over time, a TMS asset's configuration may change, including via use of spares. Configuration management helps an agency to systematically document, track, and verify changes to maintain system integrity so that the agency understands the assets it has and what to expect from them. Agencies can compile a variety of resources to support this activity, including specifications, designs, product manuals, warranties, and related documents. Configuration management activities and practices an agency may consider are described in chapter 9, TMS Asset and Resource Configuration.

Anticipated Outcome

The anticipated outcome of the activities, tools, and resources for managing and maintaining TMS assets is accurate and useful information reflecting the inventory, condition, and performance of the assets. The result is a better understanding of what can be expected from the assets and more accurate estimation of the resources needed to help the assets meet performance targets.

MONITORING, EVALUATING, AND REPORTING ON TMS ASSETS

The previous chapters describe activities, practices, and resources to identify, classify, inventory, and manage and maintain TMS asset data. Chapter 10, Monitoring, Evaluating and Reporting on TMS Assets, focuses on how this information will be used to support monitoring, evaluating, and reporting on TMS assets. Monitoring is the ongoing observation of assets' condition to determine their status. Evaluation is using the TMS asset data to understand assets' condition, performance expectations, value, and possible future actions needed (e.g., maintenance, repairs).

Reporting is an effective means of sharing information about TMS assets that may be targeted for different audiences. Reports includes outputs that help agencies understand the condition and needs of different classifications of TMS assets that may support maintenance or repairs, operations, and planning activities. While monitoring is critical to support the active management and operations of TMSs, a condition evaluation of the TMS asset may lead to an immediate report for a maintenance activity, depending on the classification of that specific asset. Activities an agency may consider include the following:

- Monitoring the condition and collection of asset information using tools and adaptation of existing resources, such as inspections.
- Evaluating assets' condition using the collected and managed TMS asset inventory data.
- Reporting to support decisionmaking about future investment, use, and composition of TMS assets within an agency.
- Using the aforementioned activities to help an agency understand and make decisions about its TMS assets and how the assets are used.

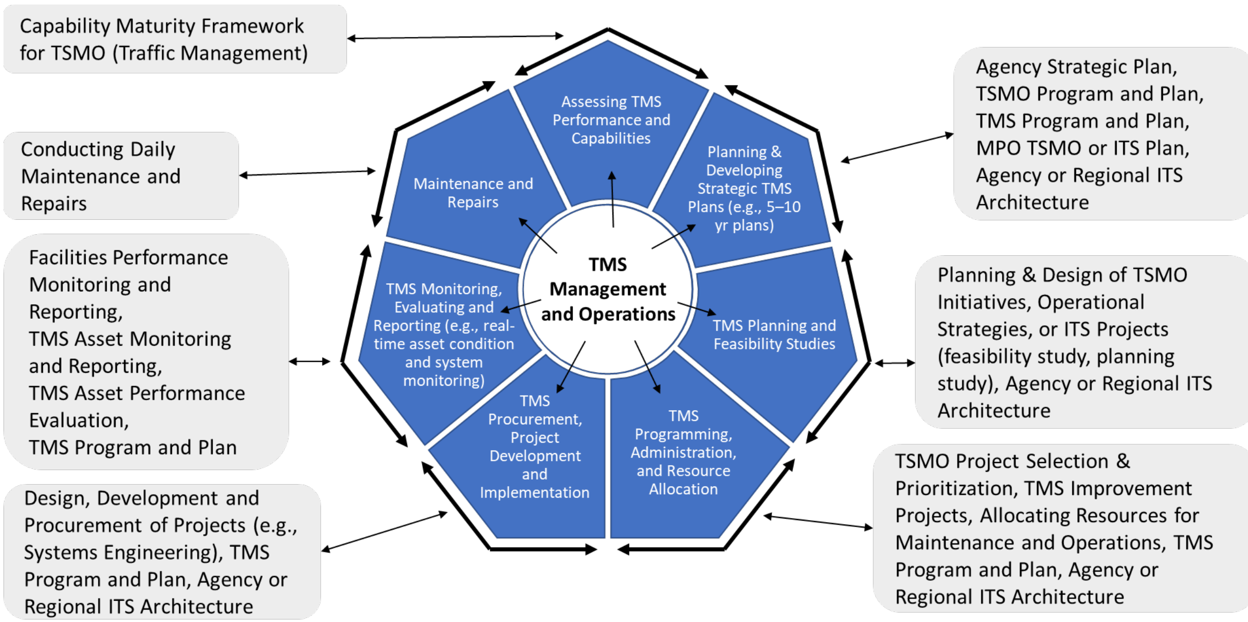
Anticipated Outcome

The anticipated outcome of monitoring, evaluating, and reporting on TMS assets is having the correct information to support managing, operating, or planning for future TMS improvements. The activities, practices, and resources support good decisionmaking for effectively managing, operating, maintaining, or improving TMS assets and meeting an agency's objectives.

THE VALUE OF MANAGING TMS ASSETS IN AGENCY TMS PROCESSES AND PLANS

Figure 3 is a conceptual illustration of agency TMS processes and plans, the relationships among, and the ways that they support the management and operation of the system.

One of the key outputs of managing TMS assets is in the processes for TMS monitoring, evaluating, and reporting, as seen in figure 3. The result of effectively managing TMS assets is an accurate understanding of an agency's TMS asset status, inventory, condition, performance, and needs. The monitoring, evaluating, and reporting processes use this accurate data to inform TMS plans and processes and to support active management and operation throughout the TMSs lifecycle, from concept (which may rely on an understanding of gaps) to retirement (which may rely on information about cost and condition).



Source: FHWA.

Figure 3. Diagram. Agency TMS processes and plans.

ADDITIONAL RESOURCES

Appendix A summarizes resources that this report draws on and that provide additional information on various aspects relevant to managing TMS assets. These assets likewise describe the value of managing assets and may help agencies make a case for initiating or expanding efforts to manage TMS assets. Agencies may consider reviewing these documents to support and augment the contents of this report as they plan to manage TMS assets.

CHAPTER 3. TMS ASSET IDENTIFICATION AND CLASSIFICATION

OVERVIEW

This chapter provides information for agencies to consider in support of identifying and classifying TMS assets. This chapter builds off the previous chapter by providing an understanding of how identifying and classifying TMS assets factors into an agency's activities to manage TMS assets. The information in this chapter also will help agencies develop a structure for performing the activities needed to manage TMS assets as described in the remaining chapters of this report.

Identification of assets entails considering all devices or elements that may be directly or indirectly part of an agency's TMS and then identifying those that can be effectively managed. As discussed in this chapter, some TMS elements may not be reasonable or feasible to manage for many reasons, such as that the effort to collect, manage, and maintain the data exceeds the potential benefits of how and when the data will be used and by whom. Additional considerations may include assets that are aging and due for retirement, or managed by other entities, or assets managing specific elements that may not effectively support other asset management activities or processes in the lifecycle of the TMS.

Classification is a technique for grouping similar types of assets to support effectively managing the range of different types of TMS assets. Classification may be done for reasons that include grouping assets with similar functions, by criticality to operations, by maintenance needs, or by geographic proximity. Identifying and classifying TMS assets allows agencies to best allocate available resources to receive the most benefit from managing TMS assets.

The following describes the relationship of the information in this chapter to TAM, as summarized in chapter 1.

> **FHWA TAMP Element: Summary Listing of Assets (23 CFR 515.9(b)-(c) and (d)(3))**
>
> Asset identification and classification aligns with one of the eight elements of a Transportation Asset Management Plan (TAMP), which is a summary of assets, including a description of the asset condition. Identification determines which assets will be included in inventory and the assessed condition, as discussed later in this report. Classification defines how each asset will be considered for management, potentially including its priority for an agency, its location and other considerations that impact its value, and how it may be managed. The challenges for agencies are to determine which assets to include in inventory and what data are valuable to collect, manage, and maintain.

IDENTIFYING TMS ASSETS

This section describes how agencies may identify TMS assets and describes associated challenges. Specifically, the section addresses the following questions in identifying TMS assets:

- What improvements does the agency expect from managing TMS assets?
- How does the agency benefit from managing TMS assets?
- Is the needed information about TMS assets available and current?

Agencies identify TMS assets to establish what assets may benefit from being managed and how asset management will benefit the systems efficiency and effectiveness. By managing TMS assets, an agency may expect to improve or maintain a devices' or elements' functionality, reliability, performance, and/or lifespan. The process of managing TMS assets provides a way to organize them and understand what resources those assets may need, what asset information can be used and shared, and how asset information could be used in other processes and decisions occurring over the TMS's lifecycle.

Asset identification leads to defining what information may be reasonable and feasible to collect to support the active management and operation of a TMS, other asset management activities, or processes and decisions in the lifecycle of a TMS. To determine the feasibility of managing an asset, agencies may consider the resources needed or the cost for collecting, inventorying, and managing the information.

An example of an asset that may be identified to be managed Is a new device, such as a CMS deployed during a recent construction project and for which the agency is expecting a high level of operational reliability or availability. An example of an asset that may not be identified for management is one whose role no longer supports agency objectives or that is nearing retirement, such as a remote highway advisory radio (HAR) that is reaching the end of its expected lifespan and that the agency may not support into the future.

Identifying assets helps an agency understand what data and information is appropriate to collect and maintain for each type of asset. This understanding can help in developing and configuring tools to manage the asset and in developing activities to collect and maintain asset data while also considering the needs of various types of stakeholders and the information that supports operations, planning, and funding of TMSs.

Identifying physical elements of TMSs to include for management may be done at the system, subsystem, component, and device levels, depending upon which level an agency believes is manageable. For example, a CMS consisting of multiple swappable devices such as a mount, logic board, sign board, and communications may be a CMS component asset composed of several devices that are managed individually.

As agencies identify TMS assets, they should consider the following levels of information:

- **System**—For high-level reporting on TMS assets, such as planning purposes and providing information to executive decisionmakers.

- **TMS subsystem**—For reporting performance and impact of TMS assets for operations activities.

- **TMS component**—For maintenance, monitoring performance, and finding causes of failures or variance in performance.

- **TMS elements and devices**—For tracking the configuration of TMS assets and for maintenance purposes where elements and devices (the discrete pieces of a component) can be replaced.

Resource constraints can limit which TMS assets an agency can manage. Agencies may identify the possible TMS assets to manage based on assets' criticality to operations, the availability of needed information to manage specific assets, and the resources available to carry out identification activities. Each agency's considerations in identifying the assets for management will vary but may include the following:

- The importance and alignment of the TMS to operational strategies and overall agency goals. Some TMS assets may have a higher priority due to their functions, location, and the dependence of other agency management systems, services, or due to the needs of other agencies or stakeholders.

- The type and quality of available or collectable data and its value in understanding the asset's condition, performance, and resources needed (e.g., maintenance, repair, replacement).

- The identification of assets to manage balanced with the available agency resources. The available resources will influence the number of assets that could be managed. The number of assets to manage will influence the data to collect, compile, manage, and maintain, and will influence the tools used to carry out these activities.

- The return on investment in managing the asset. For example, is it more cost effective to manage an asset or just replace or retire the device if a repair is needed?

- Ownership and responsibility for the asset. Is the agency responsible for the asset, or is the asset the responsibility of a contractor or other agency? For example, the Georgia DOT does not include components of the traffic signal control subsystem as TMS assets because they are managed by a separate effort. Similarly, many agencies do not identify software components as TMS assets because software components are procured and managed by IT groups or services contracts.

Utah DOT has stated that the challenge with identifying what TMS assets to manage is "determining what to inventory and what not to inventory."[11] The agency has to balance the desire to manage assets with the recognition of limited resources. As the following example shows, Utah DOT also considers whether assets can be inventoried so that the collected and managed asset data are useful in maintaining and improving assets' condition and performance. Utah DOT has developed a hierarchy to assist with identifying what elements or TMS assets to manage and what assets correlate to TMS subsystems and components, as shown in table 2.

Table 2. Asset hierarchy for identifying assets for inventory in Utah.

Asset Category	Asset Components
Cabinet	Box, cabinet-ATMS, cabinet-Signal
CCTV	Camera, camera cable, camera-Live view, camera-RWIS, encoder, remote data port
Communication	Communication hub, DSRC, media converter, modem, radio, switch
Data collection	Short-range 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, RFID reader, single-board controller, transponder signal indicator, variable toll message sign, 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, MMU, school crossing guard key switch
Signal testing	Flasher, HAWK, signal
Variable message sign	Controller, portable sign, sign
Variable Speed Limit	Controller, sign structure

CCTV = closed-circuit television; DSRC = dedicated short range communications; HAWK = high-intensity activated crosswalk beacon; MMU = malfunction management unit; PLC CPU = programmable logic controller central processing unit; RFID = radio frequency identification; RWIS = road weather information system.

CLASSIFYING TMS ASSETS

The purpose of this section is to discuss the classification of TMS assets to support their management and to provide examples of asset classification in developing a classification strategy. Per 23 CFR § 515.5:[(5)]

> Asset class means assets with the same characteristics and function (e.g., bridges, culverts, tunnels, pavements, or guardrail) that are a subset of a group or collection of assets that serve a common function (e.g., roadway system, safety, intelligent transportation, signs, or lighting).

Agencies classify TMS assets to provide structure for managing assets. Each agency will consider a classification structure that is most appropriate for that agency's TMS asset management approach. Classification involves organizing TMS assets in terms of data collection, management, and analysis, which allows agencies to do the following:

- Compare assets within their classes.
- Aggregate asset information by class.
- Coordinate maintenance needs and their prioritization by class.
- Evaluate consistently maintenance, costs, and performance by class.

As discussed in the following chapter, classification supports effective inventorying of asset information, which helps an agency understand its assets and what information the agency needs to know about the assets. Classification also provides a structure for relating and comparing information on various assets.

One means of classification is grouping assets with similar functionality or characteristics together. Examples may be grouping all CMS into the same tier or class. A reasonable expectation is that these similar assets can be compared and evaluated similarly. Table 3 is an example from the ENTERPRISE Pooled Fund Study's report, *The Evolution of Intelligent Transportation Systems (ITS) in Transportation Asset Management*, which illustrates basic classification by functionality.(12)

Table 3. Example of classification of different TMS asset types.[12]

Asset Class: Asset Type	Asset Examples
Field device: Cameras	Traffic Video detection License plate reader
Field device: Connected and automated vehicle	Roadside units (RSUs) Antennas
Field device: Emergency call boxes	Call boxes
Field device: Electronic clearance	Toll plazas Commercial vehicle ports
Field device: HAR	Broadcast units
Field device: Message signs	CMS Blank out
Field device: Sensors	Traffic detectors Commercial vehicle dimension Weigh in motion (WIM) Roadway intersection conflict warning systems
Field device: RWISs	Stations
Field device: Traffic control	Controllers Gates Lane control Preemption signals Ramp meters Reversible lane sign Signals Variable speed limit Warning flashers
Field device: Traffic detection	Detectors
Communications and networking: Communications	Fiber Copper Wireless
Communications and networking: Networking	Networking hardware Video equipment
Hardware and Software: Servers	Onsite server facilities Onsite servers Workstations
Hardware and Software: State-owned, licensed, cloud-based software	Asset management Connected vehicle Maintenance decision support systems Traffic management Traveler information

Asset Class: Asset Type	Asset Examples
Portable: Mobile device	Probes (e.g., snowplows), courtesy vehicles
Portable: Portable device	Smart work zone Arrow boards Portable CMS, cameras, etc.

Beyond grouping similar types of assets, an agency may consider other factors in classification that support an understanding within the agency of an asset's relative importance, resource requirements, or condition. Considerations in classification may also include, but are not limited to the following:

- **Risks of adverse impacts to travelers and/or the agency**—Safety-critical functions or services supported by TMSs may be placed in a higher priority tier, and assets that are critical to sustaining the management and operation of the system (e.g., data subsystem, software subsystem, communication subsystem). Lower-priority assets may include those that are in remote or less-traveled areas or provide less significant benefits to the agency and travelers.

- **Performance measures and targets for each tier or class of assets**—An agency's highest tier of assets may be those that are considered the most critical to operations. This highest tier may require the TMS to actively monitor and report on the condition of these assets. In summary, TMS assets with similar performance measures, targets, and requirements for their operating status to be actively monitored and managed may be classified into the same group. The following example from Georgia DOT shows how the agency has classified assets based on the performance measure of asset availability.

Example: Georgia DOT Prioritizing TMS Assets**[12]**

Georgia DOT has an asset classification structure based on a required uptime of the asset.[12] Georgia DOT uses their Intelligent Transportation System (ITS) Asset Management System (IAMS) to monitor performance and ties that performance to a support contract for maintenance. Specifically, the baseline asset performance levels for the 2020 contract for three different performance levels of assets are the following:

- **General** assets are targeted to have a minimum of 93 percent uptime.
- **Essential** assets are targeted to have a minimum 95 percent uptime.
- **Vital** assets are targeted to have a minimum uptime of 97 percent uptime.

This classification is the product of careful data collection and analysis over at least 10 yr. During that time, Georgia DOT has measured performance and the impacts of maintenance to determine the performance levels for assets.

- **Condition level of the assets**—As discussed in chapter 6, TMS Asset Condition, an agency can use an asset's condition to make maintenance and investment decisions. For example, agencies may use the current and projected future condition of an asset in determining when an asset may need to be retired or replaced. Condition classification may support determining the agency's approach to asset monitoring and evaluation, as discussed in chapter 10, Monitoring, Evaluating, and Reporting on TMS Assets.

- **Maintenance needs of the assets**—Assets require different levels and types of maintenance, which may be influenced by performance and condition expectations. Agencies may consider the tradeoff between level of effort to maintain and repair TMS assets by class versus the need and benefit of the TMS asset. For example, for some TMS assets that frequently fail, designating them for replacement rather than repair or rehabilitation can be more cost effective. Classification by maintenance needs may support an understanding within an agency regarding the priority for maintenance activities and investment.

Table 4 provides an example of ITS assets classified into tiers based on several considerations, including the relative importance of the asset to operations, maintenance considerations, and the performance expectations. In this example, classifying assets to the tiers is based on the following criteria:

- **Tier 1**:
  - Asset is critical to operations.
  - Minimal downtime is allowed.
  - Measurement targets are identified and tracked in real time.
  - Asset receives dedicated prioritized funding.
- **Tier 2:**
  - Asset is highly beneficial to system operations.
  - Device is repaired within reasonable timeframes.
  - Measurement targets are identified and tracked.
- **Tier 3**:
  - Asset is beneficial but not critical to system operations.
  - Item is repaired or replaced when damaged or demonstrated providing degraded performance.

Table 4. Example of ITS asset tiers.

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

Note that table 4 is an example and does not represent a specific agency's tiers. Each agency will establish its own classification structure based on what best supports managing its TMS assets. An agency may also consider classifying each asset in multiple ways that do not conflict with each other. Each classification scheme may have a specific purpose. For instance, agencies may classify TMS assets in one way for maintenance purposes and in a different way for monitoring and reporting on condition and performance. The key is to understand the purpose of the classifications, how they may be used, and to ensure the agency collects the appropriate data to support how the classification will be used, as discussed in later chapters.

TMS asset classification may be determined on a case-by-case basis by one or more factors that are important to an agency. Table 5 provides a simple example of how assets may be cross-classified based on a grouping by similarity and by priority. In this example, classes A through D may represent groupings of functionally similar assets, while the tiers may result from prioritization strategies, including how critical various assets are to operations, the availability of information on the assets, and the relative expenses for repairing and replacing the assets.

Table 5. Example of cross classifying TMSs assets.

Class	Assets				
Class A	**A-1**	**A-2**	**A-3**	**A-4**	A-5
Class B	**B-1**	*B-2*	*B-3*	B-4	B-5
Class C	*C-1*	*C-2*	*C-3*	*C-4*	C-5
Class D	D-1	D-2	D-3	D-4	D-5

Dark Gray, **Bold** = Tier 1; Light Gray, *Italicized* = Tier 2; White, Regular Text = Tier 3

Understanding what information an agency values for an asset is further discussed in chapter 4, TMS Asset Inventory; chapter 5, TMS Asset Data Management; and chapter 10, Monitoring, Evaluating, and Reporting on TMS Assets.

TMS ASSET IDENTIFICATION AND CLASSIFICATION PRACTICES

This section summarizes the activities described in this chapter that agencies may consider when identifying and classifying their TMS assets to support how their assets may be managed, their information used, and their operating status monitored:

- **Identify assets that will benefit from being managed**. Identifying all TMS elements for management might be straightforward. However, agencies risk overcomplicating their efforts by including assets that are managed elsewhere or do not reach a level that justifies being managed. Before identifying assets, an agency may consider issues discussed later in this report, such as the quality of the available data and whether the agency has the resources and tools to manage the asset.

- **Identify assets for which quality data are available and feasible to collect to support evaluating assets' operating status, condition, performance, and needs**:

    - Can the operating status of the TMS element be monitored and actively managed? What would be the expectation for that management?
    - What information can be collected to support managing the asset?
    - Who owns and is responsible for the TMS element?

- **Use an asset classification structure that supports managing TMS assets.** Classification includes effective inventorying of asset information, as discussed in the next chapter, and helping agencies relate and compare information on various assets. Agencies may consider their classification expectations for assets, the level of effort required, and their priorities when developing classifications.

- **Engage relevant stakeholders in the classification process**. Consider engaging appropriate stakeholders representing, at a minimum, maintenance, operations, and planning, to develop a classification strategy or strategies that serves all stakeholders' information or resource needs.

CHAPTER 4. TMS ASSET INVENTORY

OVERVIEW

This chapter discusses inventory, which is the collection and compilation of information that describes an agency's TMS assets and supporting resources. Inventory information for managing TMS assets should be accurate and accessible and should adequately document the information needed to understand how to manage the asset. As discussed in this chapter, inventory information typically comprises attributes including, but not limited to, asset types, quantities, locations, operational status, age, resources (e.g., operations manuals, product warranties), and other characteristics pertinent to agencies TMS asset management objectives.

The following describes the relationship of the information in this chapter to TAM, as summarized in chapter 1:

> **FHWA TAMP Element: Summary Listing of Assets (23 CFR 515.9(b)-(c) and (d)(3))**
>
> Asset inventory provides the description of the assets that will be managed. The description includes quantities, make and model, functionality, age, and other data that supports understanding the assets' value to an agency, including the conditions, functions, performance, and needs.
>
> **FHWA TAMP Element: Lifecycle Planning (23 CFR 515.7(b))**
>
> One important attribute of TMS assets is their expected lifecycle, and this chapter discusses considerations for agencies in estimating an asset's life expectancy. How long an asset will be useful helps determine costs, replacement cycles, and maintenance needs.

This chapter describes issues for agencies to consider in selecting and collecting the appropriate inventory information to manage TMS assets. The chapter discusses how agencies can use an inventory of these assets and supporting resources to understand the challenges they may encounter when inventorying their assets. The key issues addressed in the chapter include the following:

- How inventorying is used to describe and understand the status of TMS assets.
- The specific inventory information agencies may collect to support managing TMS asset condition, performance, and needs.

TMS ASSET INVENTORY

An inventory contains information on assets. The inventory may include information such as asset descriptions, quantities, make and model, or supporting resources (e.g., procurement documents, owners or operations manuals). The inventory may also include dynamic information such as asset status, condition, and whether the asset is currently in use. In the context of managing TMS assets, the inventory includes only information that supports their effective management, operation, maintenance, or repair.

Through TMS asset identification and classification, an agency may establish what assets they will manage. Inventory then determines for these managed assets what information may be useful to collect, compile, manage, and share with other entities. The information needs may vary for a subsystem and components because of how each is managed and how the information is used. For a CMS subsystem, inventory information may include quantities of CMS components that make up the subsystem. However, for each CMS component in the subsystem, an agency may inventory more detailed information, such as the make and model, age, warranty status, and other details such as individual CMS component operating status, condition, and ability to perform maintenance.

An agency may consider the following when determining what to include in its inventory:

- **What assets will be inventoried?** TMS asset identification and classification defines the assets that will be managed, and each managed asset will need inventory information for an agency to understand the asset and for managing the assets.

- **What inventory information is needed to define the asset?** When assets are identified and classified, an agency considers how it will manage, operate, and maintain the asset. These needs support identifying the information to be collected, compiled, and managed as a part of an inventory. This information may include a description of asset attributes, attribute valuation, asset classification, and other considerations such as the asset's functions, services supported, information needed to manage and operate, and location. For example, location may not be a useful attribute for managing a cloud-hosted software system, but it is useful for a TMS field device, where location helps understand the potential impacts of the environment and where maintenance or repair may be needed.

- **When is inventory information collected?** Inventory information is collected throughout the lifecycle of the asset. Agencies benefit from starting the collection of information for an asset during the procurement phase of the asset's lifecycle. Information such as make, model, date of deployment, technical specifications, and other requirements establish what is expected of the asset and its performance. Throughout the life of the asset, an agency may collect additional information via monitoring and maintenance to track asset configuration, performance, and condition.

- **What inventory information exists, is available, and is accurate?** Typically, agencies have considerable information about their TMS assets. However, that data may not be organized, available, or accurate. Warranty information may be in procurement documents but not readily available to maintenance staff, while current asset status may be monitored and reported in the TMSs software bit not captured and stored in an inventory. Is an asset identified consistently where the data are stored? If different groups have different identifiers for the same asset, how is that asset's data shared? Agencies benefit from assessing their data sources, availability, and accuracy in selecting inventory attributes. More information on data accessibility is provided in chapter 5, TMS Asset Data Management.

- **Is there a gap between the available and needed inventory information?** A gap between available and needed information may be the result of many factors, including the following:

    - Consistency in how an agency collects data. As previously discussed, reliability may be an issue if not all data are collected, compiled, and made available.
    - The capabilities of an agency's data tools. An agency may have access to needed data but not the appropriate tools to store it or make it available for others to access and use.
    - The difficulty and feasibility of collecting data. Some data may be more costly to collect than its value in managing assets. Or an agency may not have the appropriate tools to collect, compile, and manage the data. Agencies may find alternative solutions when data are not available. Agencies may also incorporate the need for additional sources of data into their planning for future TMS program activities and budgeting or allocate resources to collect needed data.
- **How often is inventory information collected?** Frequency of data collection may depend on the type of information collected and the asset's classification. Make and model of an asset is collected once. Inspection and maintenance activities for tier 1 (high priority) assets may be more frequent than for lower tier assets and thus provide inspectors with an opportunity to collect inventory information. Dynamic information such as operational status of a traffic camera may be collected several times every minute.

- **How is inventory information managed?** The collection, compilation, and ability to use inventory information may be constrained by an agency's tools and resources. In interviews, States discussed the challenges of managing the data for their changing TMS asset inventories[1]. The tools an agency uses to collect, store, and analyze asset data can influence what it includes in a TMS asset and resource inventory. Also, agencies will only benefit from collecting data that their tools are able to manage and use. Agencies do not need to manage inventory data in a single tool. However, agencies benefit from awareness of where the data are located, how data can be accessed and used, and a plan to manage the use of this information. How agencies use tools to manage TMS asset data are discussed in chapter 5, TMS Asset Data Management.

Inventory information may be different at the subsystem, component, and device levels. There is value in relating information among the levels within the inventory, such that the hierarchy from the device to component to subsystem are understood. This allows an agency to "roll up" information when evaluating and reporting on subsystems. For example, the overall condition of a subsystem may be determined by aggregating the conditions of the subsystem's components. A components' condition is dependent upon the condition of its elements. For example, a CMS component cannot operate if an element such as its logic board fails. Then, the condition of that logic board may determine the condition of the entire CMS.

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[1]Multiple State DOT interviews, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, October-November 2020.

The classification structure an agency uses for its TMS assets also determines the inventory information that is needed. For example, the assets in a class that is expected to be available 95 percent of the time may have similar inventory needs to track uptime. As discussed in chapter 3, TMS Asset Identification and Classification, classification may be based on performance targets, condition, criticality, and other factors.

TMS ASSET ATTRIBUTES

Attributes describe the characteristics of assets. Attributes can illustrate similarities and differences among assets. For example, two CMS may be similar in functionality but may differ in their manufacturer and yr of deployment. While both assets may be in the same class, an agency can use each asset's attributes to understand differences in their performance targets and how they are maintained.

As discussed in the previous section, inventory is composed of asset attributes useful for managing the TMS assets. An attribute is not included in inventory unless its purpose and value are understood. Otherwise, an agency risks increased cost and complexity in data collection and management. For example, the color of a device can be used to describe an asset, but it may not be a useful attribute for managing it.

As defined by *National Cooperative Highway Research Program (NCHRP) 08-36, Task 114: Transportation Asset Management for Ancillary Assets Attributes*, TMS assets may be defined in a hierarchical manner, and this hierarchy may help an agency understand its assets relative to other assets.[(13)] For example, within an agency, TMS may be an asset class of its own alongside other classes such as bridges and pavement. This class is then an attribute of all TMS assets. However, other levels of attributes further distinguish the TMS class. The TMS class may be subdivided into different subsystems, such as ramp metering, CMS, and traffic signal control. Within each of these subgroups, an agency may further define the assets, such as individual CMS or traffic signals.

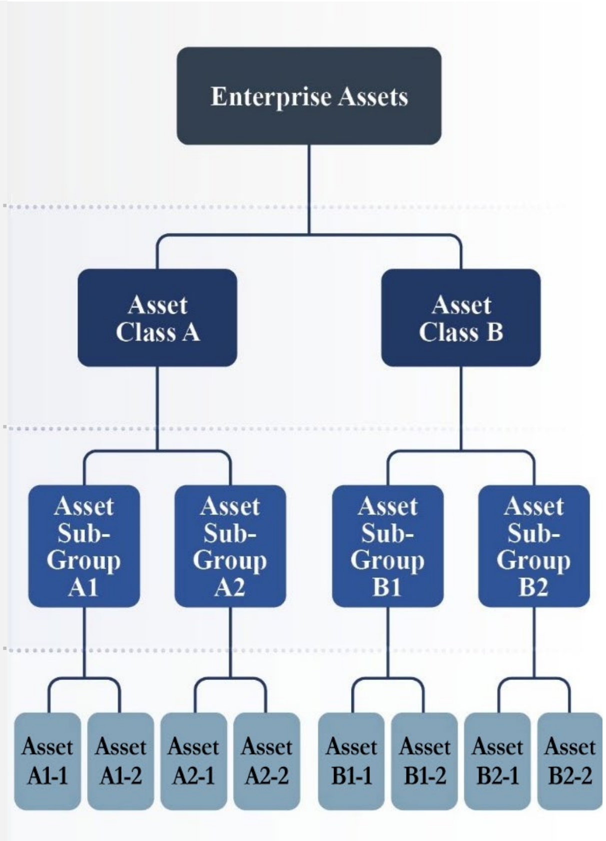
Figure 4 provides a framework example that illustrates how attributes may be structured.

Enterprise Level Inventory. Comprehensive view of all assets owned, operated, maintained and/or monitored by the agency. Allows for holistic understanding of the interaction between all asset classes and the relationship of the various asset class to overall safety, mobility and asset performance.

Asset Class Level Inventory. A collective view of all assets within a defined asset class. Allows for analysis and understanding of the operation and maintenance of all the assets holistically within the class. Example asset classes typically include bridges, pavement, traffic signals ITS devices, etc.

Asset Sub-Group Level Inventory. A specialized group of assets within an asset class within the same characteristics and function such as the type of pavement (asphalt vs. concrete) or the type of ITS device (ITS cabinet, camera, dynamic message sign, road and weather information system, smart warning device, etc.)

Asset Level Inventory (ITS Assets). The listing of individual assets and all information tracked for that asset including but not limited to general characteristics, inspection and condition assessment data, performance metrics, preventative maintenance plans, and work management information.



Source: FHWA.

Figure 4. Diagram. Asset inventory definitions framework.[14]

One example of how a hierarchical framework is applied to assets is a data frame. A data frame is the grouping of attributes with similar purposes in defining an asset and providing a structure for understanding what inventory information is needed for assets. Examples of the groupings within a data frame may include the following:

- **Asset description**—The description may be the type of asset, such as a camera or CMS. Classification may also be part of the description. Relative to figure 4, the description may be an attribute at the subgroup level.

- **Asset profile—**The asset profile collects information that belongs to similar assets of the same type, such as being of the same make and model and being procured at the same time. These attributes may also be collected at the subgroup level. 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-fail (MTTF).

    - Warranty information.
    - Documentation such as manuals for maintenance and operations, as-built diagrams, testing procedures, and photos.
- **Asset instance**—Instance data represents a specific physical asset that is deployed or stored. This data may represent the asset level, as described in figure 4. Two assets may have the same profile but are distinguished by unique instance attributes, including:

    - Asset identification (unique asset identification is discussed in chapter 9, TMS Asset and Resource Configuration).
    - Status.
    - Location.
    - Communications information such as protocols, profiles, and network addresses.
    - Installation information such as cabinets or other structures.
    - Power.
    - Procurement information such as the procurement date and contract or purchase order.
    - 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 5 illustrates the data-frame structure developed by New York State DOT for documenting ITS asset inventory in an ITS Asset Management System.

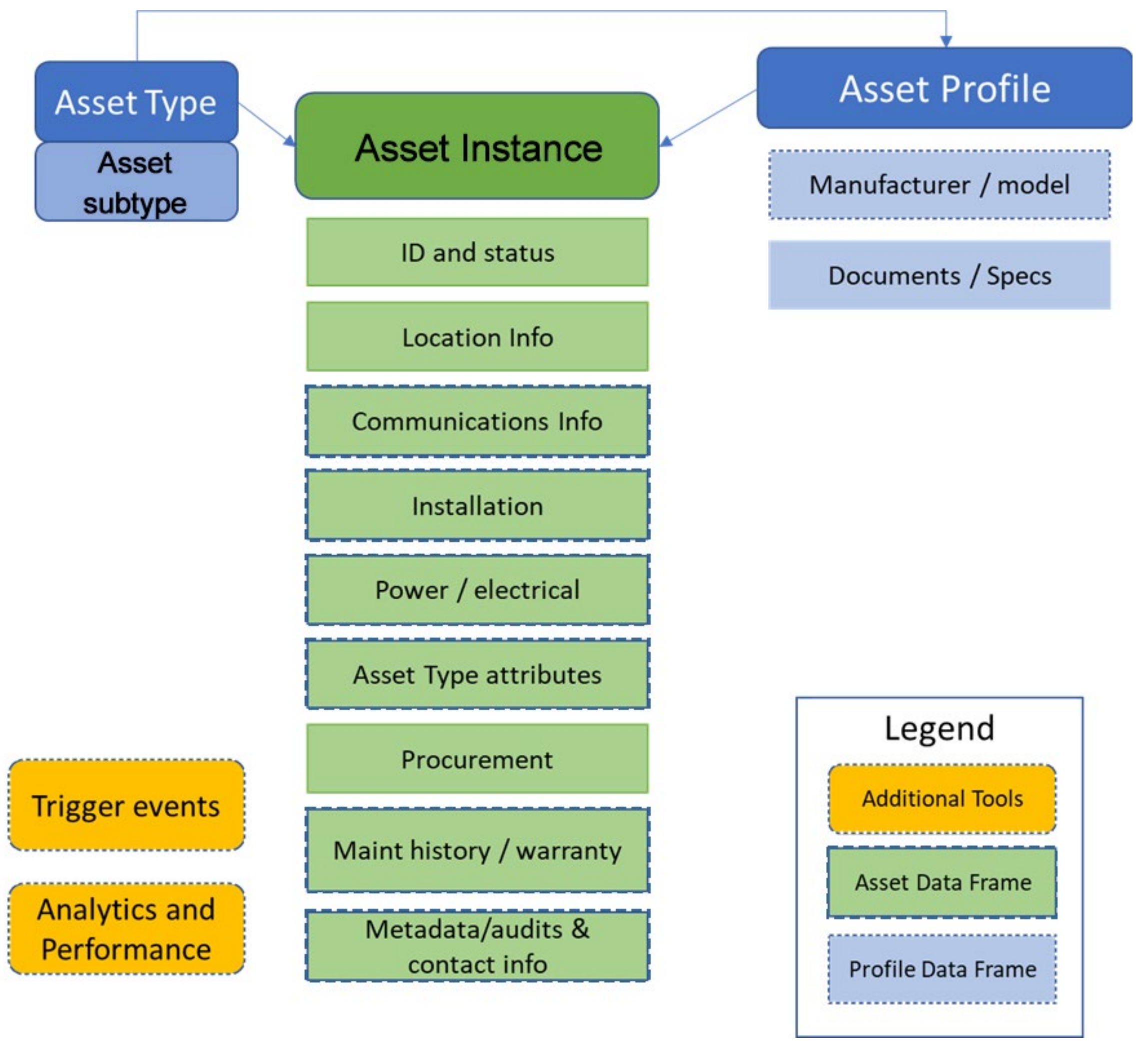


Figure 5. Diagram. Asset attribute classification for New York State DOT asset management system.

The ENTERPRISE Pooled Fund Study report, *The Evolution of Intelligent Transportation Systems (ITS) in Transportation Asset Management*,(12) mapped the potential value of different attributes to assets classified as field devices, communications and networking, hardware and software, and portable. In table 6, a "Y" represents that the attribute may be considered as having value for managing the class of TMS assets. An "N" represents that the attribute may have limited or no value in defining or understanding an asset in the associated asset class.

While table 6 is an example for agencies to consider, each agency will come to its own conclusions about the value of different attributes for managing its TMS assets.

Table 6. Attributes and potential value in managing TMSs assets.[12]

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

Y = yes; N = no.

This section has provided issues to consider in support of the elements and structure of information to include in an inventory. To create and populate an inventory of TMS assets and resources, an agency may:

- Identify the attributes that are useful to understand each managed TMS asset, such as the attributes in table 6.
- Determine the availability and accuracy of the data for each attribute.
- Create a data frame, as shown in figure 4, that includes the attributes for which data are available and accurate.

- Use the data frame to structure inventory in a data management tool, as discussed later in this report.
- Populate the data frame with attribute data using consistent practices for managing and maintaining the data, as discussed later in this report.

TMS ASSET LIFESPAN ATTRIBUTES

Lifespan describes the length of time for which an asset may be expected to be in service, meaning that the asset is still performing at an acceptable level. Lifespan provides agencies with an inventory attribute that helps in considering when to replace or retire assets before catastrophic failures or performance falls below targeted levels. This section discusses understanding the lifespan of TMS assets and how lifespan may be determined and used in managing the asset.

State DOTs are often challenged when estimating the lifespan of their TMS assets because TMS assets typically do not degrade as predictably (e.g., in a linear manner) as infrastructure assets. TMS assets are usually technology-based, with lifespans and failure modes that can be difficult to predict. The asset can fail, or a device can fail, or the asset can be impacted by external factors such as technological obsolescence. Manufacturers often provide only limited information.

The challenge in estimating TMS asset lifespan is compounded by a lack of consistent historical data collected on these assets. In addition, the fungible nature of TMS assets means an agency may have assets with similar profiles but different information in their attributes, and different expectations based on how they have been configured.

Interviews with State DOTs revealed the following strategies for estimating lifespans of transportation technologies such as TMS:

- Nevada DOT and Washington State DOT[2] indicated that their lifespan estimation is based on manufacturer guidance, which may be the manufacturer's documented estimate of lifespan, or it may be manufacturer warranty, which represents a length of time that an asset will be supported by the manufacturer with spares, replacements, and software updates, if needed.[3]
- Others, including Florida DOT,[4] Georgia DOT,[5] and Minnesota DOT,[6] use the observed historical lifespan for different asset types. For Florida DOT, detailed history on lifespan is collected to estimate life expectancy. As will be discussed later, Georgia DOT

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[2]Washington State DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, November 15, 2020.
[3]Nevada DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, October 26, 2020.
[4]Florida DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, October 28, 2020.
[5]Georgia DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, November 2, 2020.
[6]Minnesota DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, November 10, 2020.

considers spare parts availability in determining how long an asset can be expected to last.

- Pennsylvania DOT[7] uses estimated lifespans by TMS asset type as shown in table 7. These values are derived from FHWA estimates of lifespans for different device types.

Table 7. Pennsylvania DOT estimate of TMS asset lifespans.

ITS Component	Lifetime (yr)
Dynamic message sign	20
Portable dynamic message sign	14
CCTV camera	10
HAR transmitter	20
HAR flashing beacon	10
Electronic toll-tag reader	10
Wireless communications (high usage)	20

- Nevada DOT and Washington State DOT are among the agencies that use manufacturer guidance on asset service life.[8,9] By using manufacturer guidance, agencies can map life expectancy of an asset to manufacturer-recommended maintenance, with the understanding that not meeting maintenance recommendations may shorten the asset's life. However, while manufacturer guidance may be used to estimate expected lifespan, agencies frequently use the assets beyond their expected lifespan, provided an asset is still functional and with an expectation that an asset can be replaced or repaired as needed.

Agencies also consider other factors that impact how long an asset may be useful. For instance, functional obsolescence describes when an asset may no longer perform as expected due to factors such as changing standards or the unavailability of spare parts.

Assets' lifespan may continue beyond manufacturer guidance if the assets remain repairable and parts are available. For example, Georgia DOT does not identify assets for replacement unless they have a history of poor performance or repairing them becomes no longer feasible.[10] Once replacement parts are unavailable, Georgia DOT prioritizes an asset for replacement or retirement.

Other considerations that can shorten an asset's lifespan include security threats (when the asset is no longer able to operate or communicate securely) and the emergence of new technologies that may be less expensive or more effective than what is currently in use.

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[7]Pennsylvania DOT interview, conducted by Jeremy Schroeder and Matt Weatherford, October 28, 2020.
[8]Nevada DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, October 26, 2020.
[9]Washington State DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, November 15, 2020.
[10]Georgia DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, November 2, 2020.

Agencies traditionally have not had enough data to evaluate the impact of each of the factors discussed. However, agencies can create an inventory using a data frame, which provides the structure to collect data about similar assets that help agencies identify:

- The typical lifespan of similar assets.
- The impacts that have effectively shortened or lengthened the lifespan of similar assets.
- The impact of maintenance activities on lifespan.

TMS ASSET INVENTORY PRACTICES

This section summarizes the practices described in this chapter that can help agencies perform effective asset inventorying and provides considerations for how inventorying is relevant to subsequent content of this report:

- **Avoid overcomplicating inventory data.** Agencies benefit from right sizing their inventory and understanding the value of each attribute in the inventory. Acquiring, managing, and maintaining accurate asset data can be costly and challenging. Agencies benefit from understanding the value of their inventory to managing assets and then limiting the inventory to only the attributes with a clear purpose. Valuable attributes will:
    - Classify the assets.
    - Define the assets.
    - Provide an understanding of performance and condition.
    - Support being collected, managed, and maintained.
    - Support activities to manage the assets.

- **Consider how inventory data will be managed when selecting attributes.** Data management, as discussed later in this report, goes together with inventory, and an agency will benefit from developing strategies that harmonize the two. Once inventory is defined, agencies should ensure that data management activities and tools are appropriate for collecting, storing, and accessing that data. The attributes an agency identifies for its inventory will drive its TMS asset data collection. The following chapters discuss how the attributes and the data that agencies collect on those assets are used to assess condition and performance, determine maintenance needs, track and verify the configuration of the assets, manage spares, and create reports.

- **Define a structure for organizing inventory data that supports asset classification**. Developing a data frame, such as the one used by New York State DOT as shown in figure 5, gives structure to what data will be collected, how it will be organized, and how the attributes are related. Having a structure helps an agency understand its data and identify potential deficiencies. For example, once populated with data, an agency may be able to identify which assets do not have complete datasets or see where the data for similar assets are of varying quality and usefulness.

CHAPTER 5. TMS ASSET DATA MANAGEMENT

OVERVIEW

TMS asset data management describes the activities, tools, and resources that may be used to manage the identified and classified TMS assets and the inventory information that defines those assets. In developing an inventory, an agency has established the asset attributes that are useful for managing the assets and a structure for defining those attributes. Data management then is the process of populating, managing, and maintaining that inventory with accurate information that is made accessible to stakeholders.

The following describes the relationship of the information in this chapter to TAM, as summarized in chapter 1.

> **FHWA TAMP Element: Summary Listing of Assets (23 CFR 515.9(b)-(c) and (d)(3))**
>
> Asset data management aligns with several elements of a Transportation Asset Management Plan (TAMP) including managing summary of asset information. Asset information management includes developing management activities to identifying the right information to collect, apply and document curation and quality control practices, as well as incorporate tools to support these activities.
>
> **FHWA TAMP Element: Asset Management Objectives (23 CFR 515.9(d)(1))**
>
> Defining asset management objectives will help define data governance principles to involve the appropriate people, identify the right assets, and come to consensus on the roles and responsibilities, and processes needed to build continuity and sustain management of the information over time.

The purpose of this chapter is to describe the value of managing TMS asset data, the activities, resources, and tools that an agency may use for managing the quality and currency of TMS asset information. Within the context of describing data management practices, the chapter will describe examples of the issues agencies consider in support of managing information on their TMS asset.

Key issues addressed by this chapter include:

- Resources and methods for managing, monitoring, and sharing asset information.
- The roles of documentation in data collection and curation activities to support asset data sharing and lifecycle estimation.

TMS asset management resources refer to the methods for managing, monitoring, and sharing asset information for the different device types. Many tools can support collecting, monitoring, assessing, and curating data associated with tracking and logging asset conditions.

DATA PRINCIPLES

Data principles, policies, and procedures encapsulate the needs and requirements associated with managing an organization's investment in data. Principles help align the asset data management (ADM) with organizational objectives and policies. Principle statements demonstrate the value of this data to the organization.

Data principles are typically included in a data business plan. Many organizations that achieve high levels of data maturity develop a data business plan that includes principles and policies related to all types of data and management of the data lifecycle. The business plan describes the resources, roles, and responsibilities needed to invest in data collection and storage and their importance through an organization. For example, in its *Data Business Plan*, Minnesota DOT establishes data management principles(15) that state the importance of data to its business. These principles are:

- Data shall be managed as a State asset.
- Data quality fits its purpose.
- Data are accessible and shared as permitted.
- Data include standard metadata.
- Data definitions are consistently used.
- Data management is everyone's responsibility.
- Data shall not be duplicated.

Investment in data becomes a core value of the organization, worthy of continued investment. Data are elevated to a similar status as a physical asset. These specific principles also identify data as a shared resource.

Minnesota DOT's data management principles are incorporated into its asset management plans. For example, the agency established provisions for asset management data that the information managed should meet:

- Priorities and needs
- Available resources to collect and manage data.
- Quality provisions by:
    - Ensuring consistency and accuracy.
    - Documenting metadata such as data lineage.
    - Managing referential integrity.
- Access and transparency based on user roles and responsibilities.

DATA CURATION

In general, data curation describes the activities for managing the data lifecycle and documenting the activities from collection/acquisition to disposal and for enforcing all the policies, procedures, and rules in between. Elements of the curation process, as depicted in figure 6, include the following:

- **Conceptualize**—Activities for describing data needs and priorities. This stage also includes identifying data requirements: the data and their relationship to each other, supported by the classification of assets and the inventory. Conceptualization also considers the downstream data-quality needs (and the most critical quality issues) and how often the data changes and will be updated.

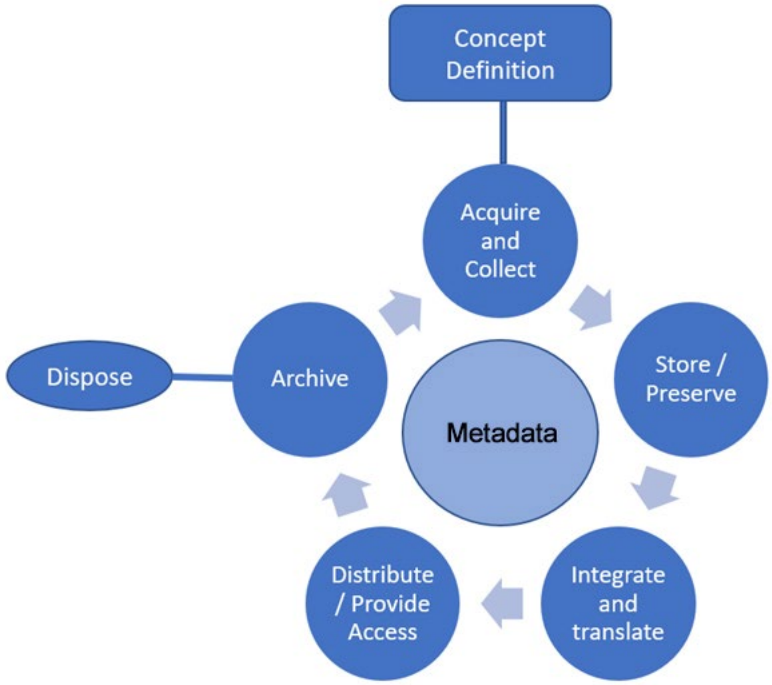
- **Acquire and collect**—Activities for acquiring accurate and quality data, including the specific algorithms, procedures, and tools that agencies use to collect and clean the raw data.

- **Store and preserve**—Activities to store and maintain configuration control of the data, including documenting metadata that describes the activities associated with the dataset. Configuration is discussed in more detail in chapter 9, TMS Asset and Resource Configuration.

- **Integrate and translate**—Activities for verifying and transforming raw data into information by matching it to other datasets. For example, this process may transform location information from spherical coordinates to street addresses or may summarize the data into ZIP codes or other aggregated areas. Creating data summaries may also require procedures to match detailed datasets to summary datasets.

- **Distribute and provide access**—Activities to share data with external groups who are granted access to the datasets.

- **Archive**—Activities to preserve the data, update the currency, and dispose of data that should no longer be stored (e.g., privacy information). This archive stage assumes that datasets may be updated, and the curation processes continue.



Source: FHWA.

Figure 6. Diagram. Data curation process.

Curation is often a gap for agencies in managing the data collected. Several organizations identify and perform elements of the activities for initializing, collecting, updating, documenting, quality checking, storing, and accessing data, but no examples exist of documented process flow diagrams that describe the entire data curation lifecycle specific to TMS assets.

Agencies have collected asset information, but the activities to collect the data are often ad hoc. Awareness of the information within the agency may be limited to a small subset of the workforce. This may prevent full utilization of the information as well as loss of knowledge during staff turnover.

Utah DOT has considered its data curation and identified the following lessons learned:[11]

- Database quality control and routine checks are important to address any inaccuracies.

- The logging system should be simple for field staff to use (e.g., tools that can log who accesses cabinets).

- Utah DOT will develop data features that directly support managing assets including: "end-of-life attributes, asset condition, quick field inventory checks, preventive maintenance model and scheduling, and quantity tracking and reports."

Two major takeaways from Utah DOT's lessons learned and Minnesota DOT's principles relate to prioritizing data needs and simplifying and automating curation activities. The process of identifying data features and priorities will be covered in the section on documentation. Simplifying and automating data acquisition will be covered in the section on asset management tools.

DATA-QUALITY FACTORS

Data quality is typically defined as information that is "fit for use," that is, the data are not *overengineered* so that they are too costly to acquire, verify, and manage and are not *under engineered* so that they do not meet the needs of critical downstream systems. Describing the measure of quality is also important. This section describes the factors that contribute to ensuring and recording data quality, including:

- **Metadata**—Documenting information about the quality, lineage, procedures, and purpose of the data characterizing the asset.

- **Referential integrity and consistency**—Ensuring the unique identity of the asset, including naming standards, system of record, and consistency in a distributed tool ecosystem.

- **Data Security at Rest and In-Transit**—Securing data, including access and protection from outside sources.

Metadata

Metadata provides information about the data. This information includes the procedures used for acquiring, storing, correcting, and processing the data. Metadata typically identifies:

- Who, when, how, and how often data were acquired, cleaned, and curated.
- The scope and extent (geographical) of data.
- The data steward contact information.
- Data ownership and license provisions.

Many data and file management systems automatically record editors, versions, and change information that contribute to the metadata. Most tools that manage asset data enforce change control procedures that record everyone who adds or edits an asset record. To that end, metadata supports data transparency, configuration control, and access.

Metadata files typically includes multiple parts, including the following:

- **General information about the dataset**—This file contains information to facilitate discovery. The file includes information about the dataset title, dataset abstract including spatial and temporal range of data, the version number, author, date published, last update, frequency of update, publisher (how to access the dataset), and other general information about the dataset.

- **Dataset provenance —**This file contains source, collection method**,** processing (e.g., cleaning, translation) and organization (e.g., schema) information.

- **Dataset fields information**—This file includes definitions of fields and their purpose, format, range and validation, and quality of data elements (e.g., accuracy, precision) included in the dataset.

Referential Integrity and Consistency

Referential integrity and consistency ensure that each asset has a unique identifier and that the data are consistent throughout the management system. Several systems start by assigning identifiers consisting of a combination of the asset type, manufacturer, and location. However, this approach falls apart when an asset is replaced or moved to another location, such as for portable message signs and spares. Although most assets include a manufacturer serial number, organizations tend to build their own conventions for assigning identifiers and affix labels such as Quick Response (QR) codes on the assets for easy tracking. For example, Utah DOT asset inventory application generates "[a] unique id [when a new data entry is] uploaded to the main Utah DOT database." (16) The New York State DOT ITS Asset Manager also assigns a unique identifier to each asset, although each region can assign a regional identifier to a managed asset.[1] Minnesota DOT adds a QR code on each asset that can be read by a mobile device (e.g., smart phone) to track maintenance activities.[2]

Asset information and identifiers are typically needed by several TMSs:

- TMSs require asset information to monitor and manage the TMC devices in the field.

- The Intelligent Fiber Asset Management System (iFAMS) is the authority for all TMS asset data for Minnesota DOT. Minnesota DOT uses its TAMS to manage asset work orders and maintenance activities.[2]

[1]New York State DOT interview, "TMS Asset Management Interview," conducted by Matt Weatherford, October 2020.

[2]Minnesota DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, November 10, 2020.

- Preventive maintenance crews update data related to assets to track maintenance activities.
- Construction projects identify assets that are impacted by work zone activities.

The Minnesota DOT example of creating and designating the *sole source of truth* or the *authority* on asset information is important when several applications need, use, and augment asset information. Inconsistencies in data can arise in the following areas:[3]

- Naming differences (e.g., Variable Message Sign (VMS) versus CMS).
- Spelling and abbreviation differences and errors.
- Use of different temporal referencing methods (e.g., weeks versus months).
- Use of different linear/spatial referencing methods (e.g., feet versus meters, Global Positioning System (GPS) coordinates versus state plane).
- Data collection accuracy and resolution differences, including number of location reference decimals measured versus stored.

Data Security

Although much asset data are available from manufacturer sites, data that provides access to an agency's internal operations and maintenance functions are sensitive. These sources of data need to remain secure, with access limited by user role. Asset information may include links to configuration and control functions. Exposing information about electronic access to equipment is critical for maintenance staff but destructive if external actors access the information. Not every person requires equal access to all the information, nor should every person viewing the information be given permission to edit or delete the information. Role-based access defines the information that individuals may create, read (view), update, and delete (sometimes referred to as CRUD).

Some agencies apply role-based access to the entire asset inventory (e.g., Minnesota DOT), while others are developing tools that provide role-based access for contracted maintenance crews to view data that they need to locate and maintain the asset and provide 'write' access to data fields to update information about their activities.

In addition to data asset security, systems also enforce and monitor asset security. For example, Utah DOT implemented a tool to secure and monitor access to assets and track access (approval and denial) of access.

Roles that are identified by several organization and that have needs to access data include:

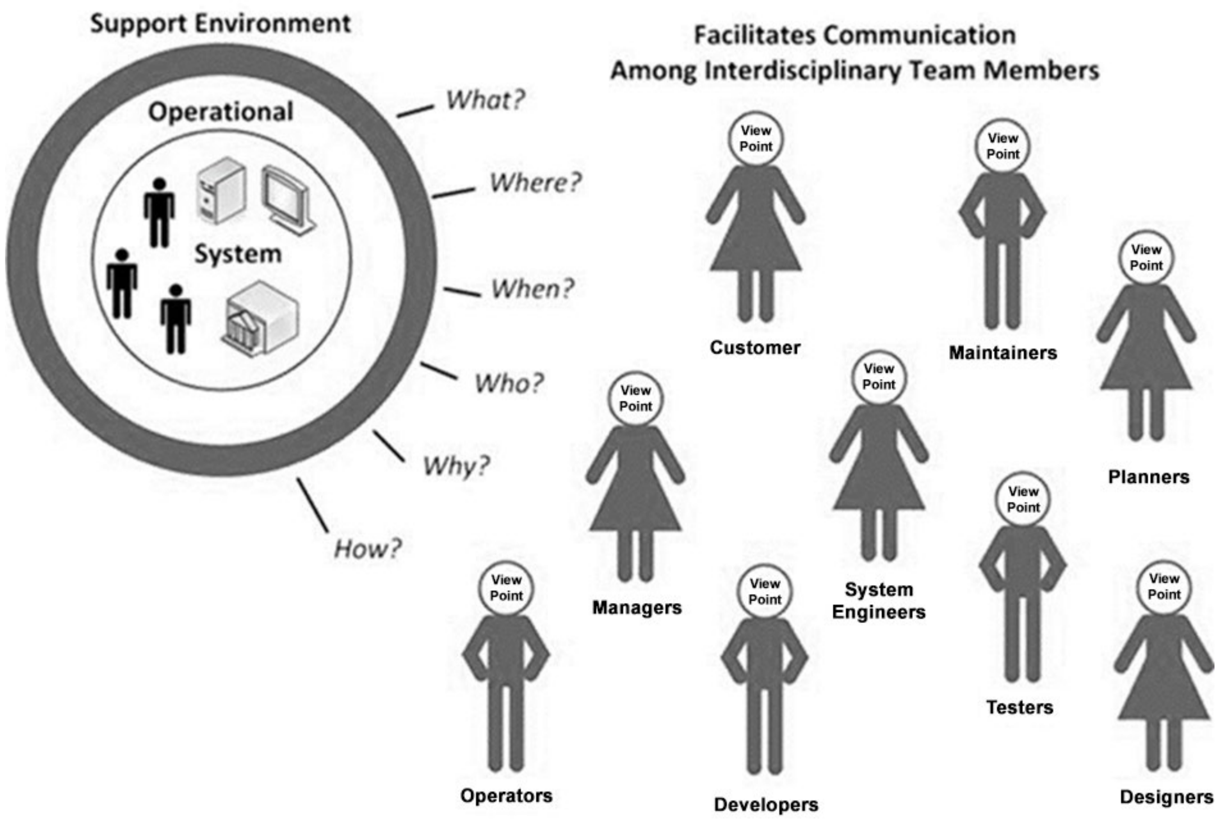
[3]Minnesota DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, November 10, 2020.

- Asset managers.
- IT staff.
- Field technicians.
- Programmers.
- TMC operators.
- Asset owners.
- Third-party contracted organizations needing access to asset information (e.g., construction projects).
- Systems interfacing with asset inventory.

Data Storage and Management

An SE-based process may help "right size" or determine the data to be collected, how its use should be managed, where it is used and by whom, how often it changes, and the responsibilities of those who touch the data. Managing asset data are resource-intensive, and the effort to collect and maintain data are costly. An agency likely does not want to over-plan the asset data attributes and quality process, nor does it want to underestimate the data to collect and miss critical attribute or accuracy information that will then necessitate recollecting and reentering data. The SE process provides a method to understand and right size the data collection, quality checking, and requirements for the TMS to manage data collection and use in a manner that ensures the data principles (quality, transparency, and access to asset information) are met.

Furthermore, the SE process facilitates discovery of information about upstream and downstream system requirements and attributes by soliciting system constraints and needs from multidisciplinary teams of producers and consumers of asset information (see figure 7). The SE process supports identifying the concept, scenarios, requirements, and descriptions about the TMS capabilities to support the data collection and archiving process. This process may consider agency and TMS policies, procedures, resources, and assumed capabilities needed to collect, monitor, assess, and manage data on TMS assets. In addition, the data collection and archiving process also identifies critical information needs such as asset location, characteristics, condition, and lifecycle information.



Source: FHWA.

Figure 7. Diagram. SE process facilitates communications among interdisciplinary team members.[(17)]

An SE process is appropriate for determining asset data sharing needs, methods, and requirements for TMSs. Specifically, using an SE approach as described by the International Council on Systems Engineering (INCOSE) answers key questions that include the following:[(18)]

- Who are the stakeholders and what are their needs? For example, who needs asset inventory, condition, and lifecycle cost information, and to what level of accuracy?
- What conditions and performance measures are needed and what data are needed to generate those measures?
- What missing information is needed to generate the measures?
- What activities are needed for managing the data (asset and attributes)? Who is responsible for developing governing rules for curating those activities? Addressing these questions will ensure consistency related to data quality and integrity across data collection and processing methods.

DOCUMENTATION OF TMS ASSETS AND RESOURCES

Accompanying the SE documents are products that detail TMS requirements/specifications and TMS design, installation, procurement, operations, and maintenance activities. Additional documents may include procedures for collecting data, standard operating procedures, data dictionary and schema, and training materials.

For example, to keep the asset database current, Minnesota DOT requires contractors to submit final as-built plans. The agency needs to know what was done and where it was done, especially for underground installations. The templates that standardize the deliverable format for each asset type are listed on Minnesota DOT's As-Built Deliverable website.(19) The documents that can be viewed by the public are hosted on Minnesota DOT's online asset management platform, eDOCS.(20)

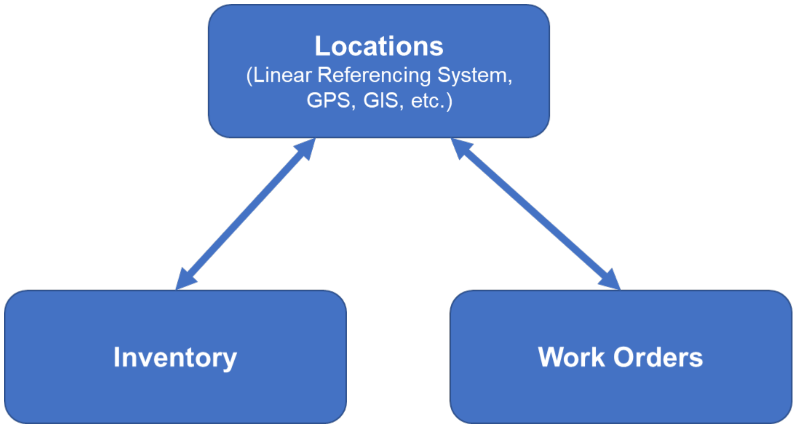
In addition, Minnesota DOT's policy hub web page includes a repository of all agency policies by topic. For example, under data management policies, Minnesota DOT has established a data-stewardship policy related to managing assets.(21)

TOOLS FOR MANAGING TMS ASSET DATA

This section provides an overview of the commercial, open source, and agency-developed tools that agencies use to manage TMS asset data. A wide range of tools are available that provide various capabilities and functions to support monitoring, collecting, and managing TMS asset data.

Several applications combine managing TMS asset data with tracking condition and maintenance activities.

These tools may be operated as a service (e.g., software as a service (SaaS)), reside on the "asset manager's" desktop (e.g., spreadsheet), or be commercial of the shelf (COTS) software at the DOT's TMS. The tools may include interfaces that link to other tools including TMSs, maintenance management systems, analysis tools, or they may include software that performs those functions. Agencies may acquire and deploy tools at different times, requiring integration for the tools to work together and work with a TMS. For example, figure 8 shows the relationship model developed by Utah DOT for its Asset Information Management System deployment. The model identifies several tools that share information.(16)



Source: FHWA.

Figure 8. Diagram. Relationship of Utah DOT databases containing TMS asset data.

Agencies may consider many tools for managing and monitoring assets. The types of tools range from customer asset management tools to ad hoc spreadsheets and GIS files. As an organization becomes more mature in its data governance, it begins to adopt robust and automated software to manage data. Software tools extend from basic spreadsheet asset records storing general information about assets (e.g., asset inventory), including their installation location (e.g., GIS), to tools that monitor the real-time asset conditions and performance.

Table 8 summarizes high-level functions and capabilities of asset management modules and related management systems that support risk and performance assessments of TMS assets.

Different tools serve different roles, even as many tools have overlapping capabilities. A system view is necessary to understand system roles and responsibilities, upstream data collection quality, downstream data needs, data sharing constraints, and interoperability with respect to user needs.

Table 8. TMS ADM tool types.

Tool Type	Tool Examples	Description
Asset inventory	Spreadsheet, database, and custom and COTS asset management software.	Stores data about asset attributes. Data may include quantities, asset characteristics, key dates for procurement and maintenance, warranty information, etc.
Asset condition and status	Maintenance Management System (MMS, spreadsheet, database.	Manages information about the condition and status of asset and records maintenance activities related to an asset (within a system). For example, the maintenance system may be used to record information about preventive maintenance activities, changes to light bulbs in a CMS, security patches, software updates, and data content uploads.
Maintenance tracking	MMS, database, COTS asset management tool.	Issues and tracks maintenance tickets about asset.

Tool Type	Tool Examples	Description
Status monitoring	ATMS, network performance monitoring	Monitors health and function of asset. May include several types of monitoring software such as communications monitoring and internal device monitoring software.
Resource	Spreadsheet, database, custom and COTS asset management tool	Manages resource utilization and lifecycle of asset and system in which it operates.
Geolocation	GIS and Linear Referencing Systems (LRS)	Associates an asset with one or more geographic references and can display the asset on a map. Allows assets to be spatially related to the road network and other assets.
Mobile data collection and auditing	MMS, custom mobile applications	Mobile data collection used by staff to collect and updated asset data and verify data about an asset in the field. Maintenance personnel may use these tools to track removal and replacement of assets (or subassemblies of assets) and track the changes in the inventory, work order, or maintenance management function.
Performance management (e.g., dashboard, visualization)	ATMS, custom and COTS asset management software	A visualization that shows information on the asset related to its performance. Depending on the metrics and management system, the dashboard may show inventory summaries, real-time health statistics, maintenance and work order report, or other visualization methods.
Valuation; budget forecasting	Spreadsheets, databases, custom and COTS asset management software	Manages and processes the value and forecasts lifecycle (repair/replace) of each asset or group of assets.
Risk	Spreadsheets, databases, and custom and COTS asset management software	Based on asset activities and history (maintenance, monitoring, location). Generates replacement curves of individual assets or groups of assets and tracks the estimated preventive maintenance or failure rate of the asset or group of assets.

Considerations for TMS Data Asset Management Tools

In addition to considering the diverse functions offered by various tools, agencies may consider a range of factors in determining the needed requirements, functionality, and expectations of a tool or tools, including:

- **Existing tools**—An agency already has software systems that are managing TMS asset data and that may have untapped functionality. Before building or procuring new, resource-intensive systems, an agency may consider where its data resides and what functionality the current tools can provide. Some States have chosen to expand existing systems, such as modifying a traffic signal management database, to accommodate the unique needs and attributes of TMS because the existing systems provide continuity and lower cost than procuring new tools.

- **Open architecture** (access to exchange information with other applications)—Initially, a Georgia DOT contractor owned and operated the agency's asset management tool. When the contract expired, Georgia DOT was left with data that was difficult to access and use without the contractor's application. The agency could not access the data because no "open architecture" methods were in place. Such methods could include comma delimited file downloads, database schema access (Structured Query Language (SQL) queries), or data feed specifications such as Keyhole Markup Language (KML) or Geographic JavaScript Object Notation (GeoJSON).[4]

- **Alignment** (integrity of references and consistency of attributes with other TAM efforts and tools)—Many data live in multiple systems or are managed by different units within an organization. Even georeferences may differ between systems. For example, some New York State DOT systems use their linear referencing system to map asset locations, while others use latitude and longitude to locate assets.[5] Documentation that is useful to develop to ensure alignment include:

    - A data dictionary with attribute definitions, formats, and enumerated values.
    - Definitions of naming conventions for references (asset identifiers).

- **Cost**—This consideration includes the capital investment and expenses related to managing the tool over its lifecycle. Specifically, an agency may consider the business structure of the tool's procurement via the following questions:

    - What is the cost structure of the software (SaaS, on-premise with license fee, custom with technical support)?
    - Can the agency configure the tool, or does it require a change order for each update or change?
    - Is the interface license restricted or open?

- **Expandability**—Tools should have the ability to expand and provide capabilities to address an agency's data needs. Does the agency have other needs that either this or other tools can accommodate? To that end:

    - Can the data fields be configured and updated to accommodate new assets or additional attributes and values?
    - Can information about new or updated assets be exported and imported?
    - Can secure access to the asset data be enabled based on user roles?

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[4]Georgia DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, November 2, 2020.

[5]New York State DOT interview, "TMS Asset Management Interview," conducted by Matt Weatherford, October 2020.

- **Sharing infrastructure** (understanding who will enter and use data)—Many tools now include mobile interfaces that allow maintenance staff to automatically record information such as asset location and asset photos. Staff may also be able to access asset information in the field, such as asset specifications, documentation, and records of previous maintenance. This information may be valuable for configuration verification as discussed in chapter 9, TMS Asset and Resource Configuration.

MANAGING ACCESS AND USE OF TMS ASSET INFORMATION

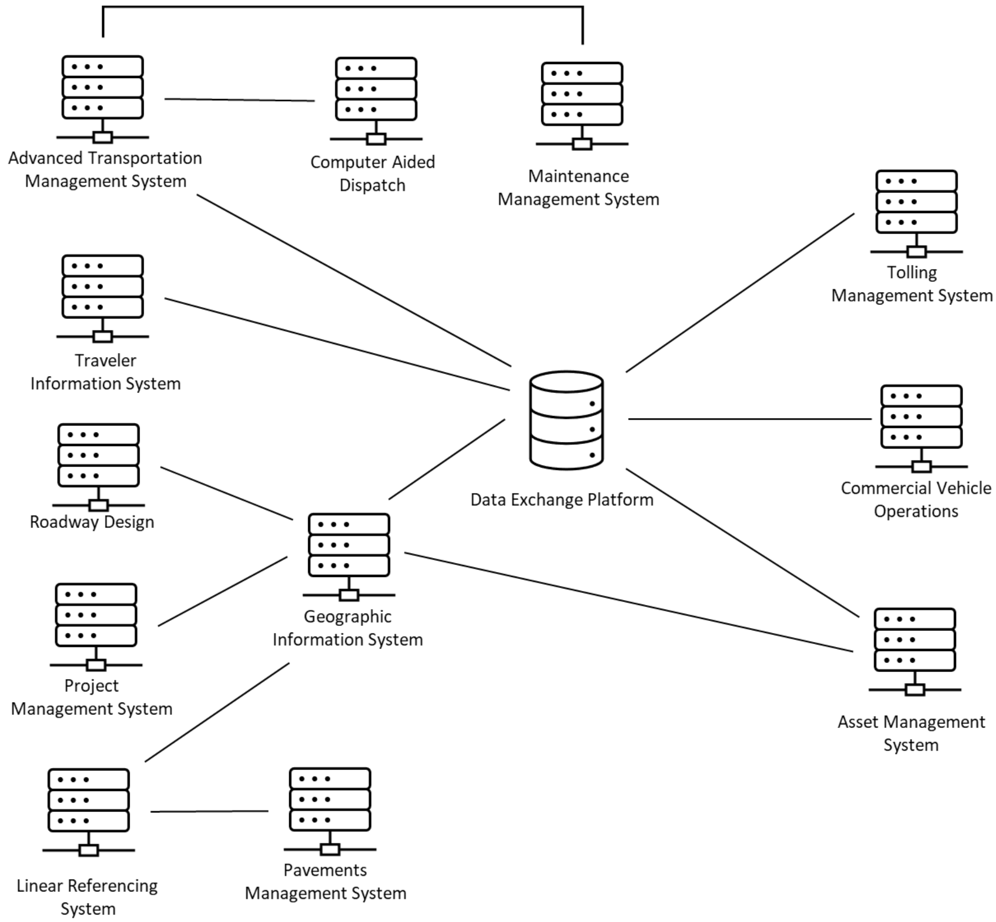
Access to the data that describes the TMS assets is a priority for managing those assets. Data should be available to people who base their actions on information like quantities, locations, condition, and performance. Similarly, staff who will provide updated data, such as when assets are deployed, maintained, and retired, need access to the data. This section describes practices for managing access and use of asset data.

As discussed in Tools for Managing TMS Asset Data, agencies typically use many tools to manage their asset data through installation, monitoring, management, operations, and maintenance cycles. To that end, sharing data—whether related to collecting asset condition information from monitoring resources or disseminating stored condition information to maintenance crews, operational systems, or budgetary assessment tools—is a key part of managing TMS assets. In the case where asset inventory, performance, work order and maintenance information are collected using different tools, methods are developed to share information.

Access methods and functions typically include the following:

- Open architecture Application Programming Interfaces (APIs).
- Flat files such as comma delimited files, KML/shape files with attributes.
- Upload versus download functions (using custom extract, load, and transform functions).
- Upload to inventory for new data or major changes to data; requires authorized users to change information.
- Download from inventory to share information with other tools (related to asset operations, monitoring and maintenance, or other databases such as safety, work zone, etc.). May require query capability to drill into specific data needs, such as identifying TMS assets in an intersection undergoing construction to understand the impact of asset operations (e.g., signal system, assets in an ITS cabinet).

Figure 9 depicts an example of the relationship among common transportation agency systems that have, use, and share asset data. Note that each agency has different systems, and their relationships may be different or nonexistent. However, knowing where an agency’s datasets reside, their accessibility, and their relationships, including the “owner” or sole source of truth of different data, is valuable.



Source: FHWA.

Figure 9. Diagram. Example agency system interconnect diagram.(22)

Challenges in sharing data include:

- Knowledge of master reference data and source of truth is often limited, making it difficult to share data and know what is duplicated versus what is original.
- Information on quality and currency of data may be missing.
- Common attributes, naming conventions for identifiers, spatial referencing methods and a data dictionary may be difficult to establish to ensure consistent use through multiple applications.

TMS ADM PRACTICES

This section summarizes the practices described in this chapter that can help agencies perform effective TMS ADM:

- **Identify existing data management activities including data management plans and principles**. Data are agency assets, and their use requires an understanding of their purposes and needs to support agency objectives. Agencies may consider aligning their

TMS ADM with broader data management plans when they exist. Consider the Minnesota DOT data principles and how they are applied across data within the agency.

- **Define roles and responsibilities for data management**. Understanding the roles and responsibilities of the TMS asset data stakeholders supports data quality. The data-quality expectations can be established so that stakeholders understand and agree to committing the resources required.

- **Treat data as an asset, and plan to manage the data over its lifecycle.** Agencies may consider how data are treated from inception through retirement and whether the curation process adequately values and utilizes its data throughout the data's life.

- **Identify existing tools and systems that store data.** Agencies already have data stored in tools that provide many of their needed functions. They will benefit from identifying data gaps and identifying how existing tools may be modified or other tools may be procured to fill the gaps and otherwise improve TMS ADM. Agencies also may consider expanding their existing tools rather than procuring new tools, when feasible.

- **Establish data-quality expectations.** An agency benefits from considering the level of data quality needed and determining the resources and activities required to achieve that level. In data-rich environments, such as TMS assets, data management may be complicated by working toward quality levels that are higher than needed. Agencies also may consider creating a master referencing database as the sole source of truth for asset identification keys. More information on unique identifiers is discussed in chapter 9, TMS Asset and Resource Configuration.

Also, a key to data quality is ensuring consistency in how data are recorded. For example, small errors can affect an agency's ability to compare and analyze data. Examples include naming differences, spelling errors, computational differences, use of different linear/spatial referencing methods, data collection accuracy and resolution differences, precision, and scaling differences in storing data.

- **Start data management with SE and documentation**. Georgia DOT has used the SE process to define the performance of technology and the tools to collect data, monitor performance, and evaluate the condition of the assets. The SE process integrated TMS ADM into how the agency manages the assets, including defining the data collection processes.

- **Data access and sharing**. Developing a data flow diagram helps an agency understand who will be using TMS asset data and where data originates. Agencies may also consider developing role-based access to data to support data access and integrity. Role-based access supports users having the data they need to access and supports data integrity by limiting who may change data.

CHAPTER 6. TMS ASSET CONDITION

OVERVIEW

The conditions of TMS assets are critical inputs to prioritization and allocation of available resources (e.g., maintenance, repairs, and improvements) and the real-time management and operation of a TMS. This asset information is also a critical input for the strategic planning, program planning, management, and transition to the next generation of an agency's TMS assets as it explores options to modify, upgrade, or replace TMS assets or specific subsystems (software, data, telecom), components, or field devices. The purpose of this chapter is to discuss the activities, tools, and resources for assessing asset condition information and how agencies may use the information in managing TMS assets.

The following describes the relationship of the information in this chapter to TAM, as summarized in chapter 1.

> **FHWA TAMP Element: Measures and Targets for Asset Condition (23 CFR 515.9(d)(2))**
>
> This chapter discusses how agencies define TMS asset condition and how that information is used to support managing the TMS assets. Inventory data, such as age or performance, may be used to assess TMS asset condition, which may then be used to determine the needs and performance expectations for the assets.

The key issues addressed by the chapter are the following:

- Defining condition of assets and its role in managing TMS assets.
- Discussing agencies' activities and practices for assessing and using asset condition information.
- Considering the factors that impact the condition and lifespan of TMS assets.

The focus of this chapter is how collecting, configuring, preserving, and using data on the condition assets contribute to effective management of these assets.

TMS ASSET CONDITION CONSIDERATIONS

The purpose of assessing asset condition is to develop an understanding of the needs of those assets. Condition supports:

- An understanding of the performance expectations of a single asset, an asset class, or of TMS assets.
- Estimating maintenance and replacement needs for the assets. Assets an agency deems to be in poor condition typically need replacement sooner and/or need more maintenance activity to keep them operational.

- Impact on overall operations. An agency whose TMS assets are in generally good condition will see their TMS support operations work as expected.

The identification and classification of TMS assets discussed in chapter 3, Traffic Management Systems Asset Identification and Classification, provides a structure for defining which assets an agency seeks to collect, process, and use information on the condition of specific TMS assets. If an agency identifies an asset to be managed, the agency will need to understand the asset's condition so that it can develop a strategy to manage, maintain, or improve that condition.

If assets are classified by tiers, tiers may indicate the criticality of the asset. In that case, the highest-tier assets are those most important to operations, and they may necessitate a more accurate understanding of condition and a focus on maintenance activities to maintain those high-tier assets in better condition.

Condition Based on Age

Agencies have traditionally lacked information and data to assess the condition of TMS assets, so many agencies have used age as a basis for managing assets. The asset age may be compared to the expected lifespan or derived from manufacturer guidance or agency observation to estimate condition.

Example: Nevada DOT ITS Condition Assessment(23)

Nevada DOT uses age to determine the condition of TMS assets. TMS asset conditions are determined to be one of the following:

- **Good** = within the first 80 percent of their expected life.
- **Low risk** = between 80 percent and 100 percent of their expected life.
- **Medium risk** = between 100 percent and 125 percent of their expected life.
- **High risk** = have been in use more than 125 percent of their expected life.

As shown later in this section, this condition information is used to determine the maintenance needs of the assets.

Nevada DOT uses the condition assessment described in the preceding example to plan maintenance activities for each asset. High-risk assets may receive more inspections and be expected to require more major maintenance activities on average. The agency estimates that high-risk assets also need more frequent replacement, all of which results in a higher expected cost to maintain a high-risk asset than assets in better condition.

Condition Based on Performance

As agencies collect and manage more and better data, they may include other considerations in assessing condition. This approach may prove effective because the nature of TMS assets is to degrade less predictably than traditional transportation assets. Considerations an agency may have in assessing condition include:

- **The performance targets for the asset**—Each agency may have different expectations and therefore establish different criteria for its performance, such as availability and MTTF. A simple asset with a proven track record may have a much higher expected availability than a more complex TMS asset or one based on emerging technology.

- **Maintenance**—Alongside criticality, an agency may consider the maintenance requirements of an asset. An asset that has not been maintained in accordance with the agency's maintenance guidance may be considered in worse condition and in need of more future maintenance or earlier replacement. Also, an asset that is accessible and can be repaired or replaced quickly and inexpensively may have a high expectation for performance. For example, an asset that can be quickly repaired and replaced will result in higher availability. An asset that is complex and difficult to repair, such as a CMS in a challenging and remote location, may be expected to have lower availability because it will take longer to access and repair.

- **Environment**—The environment in which an asset operates may affect its performance. For example, an imbedded detector may fail more frequently in a snowy or wet climate than one imbedded in a warm, dry environment. An agency may consider tracking the asset environment as an attribute with an impact on performance.

- **Changing performance targets**—As technologies mature, they may become more robust. Similarly, as agencies manage TMS assets over time, they can improve their practices in managing assets and become comfortable with increasing performance targets. Georgia DOT had three consecutive ITS maintenance contracts, and with each one they have increased the minimum performance targets (e.g., from 90 percent availability to 95 percent availability for the same class of assets).[1] Georgia DOT has increased their expectations by improving monitoring and maintenance practices and by developing a better understanding of the needs of their assets. Agencies will benefit from using the TMS asset data to assess when and how to adjust how they assess condition.

Condition by Use

Similar to how an agency may use different classifications for assets for different purposes, an agency may assess condition uniquely for different purposes. While availability may be important to staff in a center for a TMS, the level of maintenance required for a specific asset may be how an agency uses condition information in how it manages an asset.

[1]Georgia DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, November 2, 2020.

Example: Virginia DOT TMS Asset Condition Rating [24]

Virginia DOT classifies its TMS assets into two components: the ancillary structure and the technology component (e.g., signal, controller, camera). For the ancillary structure, Virginia DOT assesses the condition of the superstructure (cantilever, parapet mount, and/or span wire) and the substructure (foundation). The condition ratings for ancillary assets are divided into five categories: good, fair, poor, critical, and failed condition. At the time of each inspection, an inspector assigns condition ratings to describe the major structural components of the asset. Condition ratings are based on criteria like those defined by FHWA for bridge inspection, and components are inspected for condition every 4 yr.

TMS ASSET CONDITION DATA

This section describes the value of asset condition in managing TMS assets and the activities, practices, and resources that support documenting asset condition. Collecting asset information is critical to assess asset condition, maintenance history, and to develop a preventative maintenance cycle. Information on the current condition and changes over time contribute to the information needed to analyze asset condition over the asset's lifespan. This information also provides data that supports the lifecycle maintenance and replacement costs, as discussed in chapter 7, TMS Asset Data Maintenance.

Asset Condition Information

As discussed in chapter 4, TMS Asset Inventory, useful information for understanding assets has a clear purpose and can be reliably collected. Agencies are challenged to right size their inventory information so that the inventory is manageable, with benefits derived from the data and its analysis greater than the resources required to collect it.

With this challenge in mind, agencies may consider the following information as useful to assessing the condition of its assets:

- Data collected during procurement and from the manufacturer such as:
  - Specifications to define performance targets and functionality.
  - Make and model to classify the asset and compare and relate its performance to that of other similar assets.
  - Operating systems and firmware to identify needs for updates and security vulnerabilities as software and firmware become obsolete.
  - Dates of procurement and deployment to understand asset age.
  - Manufacturer guidance on maintenance.
  - Expected lifespan, whether from manufacturer guidance or experience.
- Maintenance history over the lifespan of the asset, such as:
  - Maintenance activities on the asset in comparison to the recommended maintenance, such that the agency can assess whether assets have received maintenance according

to guidance. An agency may consider the cost of maintenance in its decision of whether to maintain an asset's condition or allow it to degrade prematurely.
  - Configuration changes. Changes include the replacement of parts or other activities like bypassing certain functionality when parts are no longer available. Inspections allow agencies to verify that an asset is configured as expected or to identify changes that were not properly documented.

- Operational status of the asset, such as:

  - MTTF, which indicates how long an agency can expect an asset to be available, on average, between failures.
  - Availability in terms of what percentage of time the asset is available and providing its functions.
  - Frequency of failure, which indicates how often an asset fails. The failures may show patterns, such as more frequent failures during severe weather.
  - Work orders, which can provide information on the status of maintenance actions requested for an asset, how long they are taking to complete, and their impacts on asset performance.

Determining Condition from Part of an Asset

California DOT (Caltrans) has documented that some States assess component condition based on an element or device within an asset.[25] States derive condition information based on experience of what part is likely to fail first and on what can be repaired. An example regarding CMS condition assessment is shown in table 9.

Table 9. Asset devices used to determine CMS condition.[25]

State	Uses Multiple Components	Component Description	Life Span of Each Part Tracked	Part That Determines Overall Condition
Illinois	—	—	—	Message board
Nevada	X	Inspections Minor and major repairs Replacements	—	Developed a deterioration model using a transition probability matrix
Oregon	X	Major components only.	—	N/A—currently only has a condition rating for traffic signals
Pennsylvania	X	Sign type Structure type Power type Cabinet, controller Uninterruptible power supply (UPS) Modem Switches	—	Sign age

State	Uses Multiple Components	Component Description	Life Span of Each Part Tracked	Part That Determines Overall Condition
South Dakota	X	Support structure. CMS controller and display Power Communications	X	CMS controller and display
Utah	X	Controller Sign Communications equipment	X	Implementing new system that rates each component on a scale 1 to 5 (1 = dead/failed; 5 = excellent/new condition). Overall condition Average of each component condition
Virginia	—	—	—	Overall look at age and condition Manufacturer support New opportunities Legacy support Any efficiencies
Wisconsin	X	Sign bridge structure Sign housing LED board Power supplies Controller Cabinet/components	X	No response

X = affirmation
— no data.

USING TMS ASSET CONDITION

This section provides an overview of how an agency may use condition information in managing TMS assets. The condition, when derived accurately, can be used in determining asset needs and supporting decisionmaking about resource allocation and reporting on TMS assets.

Determining Asset Needs Based on Condition

The primary purpose of asset condition information is to support what agencies may expect from their assets and what management and resources (e.g., needed maintenance, repairs) may be needed to meet desired performance targets. An agency may develop performance measures and criteria on the condition of assets based on the available data and how this data can inform how they manage other assets. Oversight necessary to sustain desired conditions may include maintenance, replacement, and retirement.

The following example from Nevada DOT illustrates how maintenance needs for assets are derived from their condition assessment, which agencies then use to estimate the maintenance costs of the assets, as follows.

Example: Nevada DOT Maintenance Needs Based on Condition and Derived Cost[(23)]

As discussed earlier in this chapter, Nevada DOT uses asset age to assess condition. The condition is then related to maintenance needs by asset type as shown in table 10. Here, the agency expects 25 percent of high-risk closed-circuit television (CCTV) cameras to need major maintenance in the next yr, while those in good condition are expected to need none. Similarly, 10 percent of high-risk CCTVs are estimated to need replacement in the next yr, while other condition levels are expected to need none.

Table 10. Nevada DOT maintenance needs for CCTV cameras by condition.[(23)]

Maintenance Type	Good Condition	Low Risk Condition	Medium Risk Condition	High Risk Condition
Inspection	100%	100%	100%	100%
Minor	—	10%	30%	10%
Major	—	—	10%	25%
Replacement	—	—	—	10%

— no data.

Table 11 shows the estimated costs by maintenance activity for CCTV in District 1 of the State. The State can estimate these costs separately for each district to reflect variations in geographic area and other factors in maintenance. Based on these cost estimates, Nevada DOT derives that a high-risk CCTV camera in District 1 will have an average of $3,015 in maintenance needs. This value is calculated based on two inspections at $300, a 10 percent chance of minor maintenance, a 25 percent chance of major maintenance, and a 10 percent chance of replacement.

Table 11. Nevada DOT estimated maintenance costs by maintenance type and per unit for closed-circuit television cameras.

Inspection	Minor	Major	Replacement
$300	$1150	$4600	$11,500

Supporting Decisionmaking

The need for and cost of maintenance determined from asset condition information, as shown in the Nevada DOT example, can be used to support decisionmaking on the most effective approach to asset maintenance or determining when to replace an asset. As condition deteriorates and the cost to maintain an asset increases, continued use of the asset may not be cost effective. Cost analysis is discussed in more detail in the next chapter.

Reporting on TMS Assets

Condition is an attribute of assets that can be understood by a wide audience. Reporting allows agencies to understand their TMS assets similar to how they report on and manage other assets. Reporting is discussed in more detail in chapter 10, Monitoring, Evaluating, and Reporting on TMS Assets.

CONDITION CHALLENGES AND OPPORTUNITIES

This section discusses the potential issues, challenges, and opportunities to condition assessment for TMS assets as reported in the ENTERPRISE Pooled Fund Study report, *Best Practices in Future Proofing for Emerging Technologies*.[(26)] TMS assets face a set of challenges that differ from those faced by traditional transportation assets:

- **Natural challenges—**Severe weather and extreme temperatures may affect TMS asset performance (e.g., flood, rockfall, avalanche, landslide, heat, cold).
- **Functional performance challenges—**An existing system may function less efficiently compared to competing solutions (e.g., by not keeping up with trends to advance to current technologies).
- **Financial challenges—**Costs to continue operations may exceed available funds, either due to cost increases or reduction in agency funding allocations to the system.
- **Political or legislative challenges—**Risks may be caused by a change in legal status or licensing (e.g., the Federal Communications Commission (FCC) reallocation of the 5.9 GHz spectrum from DSRC to cellular vehicle-to-everything communications).
- **Agency or department policy decisions—**Changes to agency policies or procedures may negatively affect TMS assets.
- **Cybersecurity challenges—**TMS assets could be a target of malicious attacks, either directly to the TMS asset or the data supporting them.

Once an agency has identified the TMS assets' challenges and issues, it may consider how to use these factors in assessing the condition, performance thresholds, and possible management actions.

The high-level process that follows outlines how agencies can mitigate challenges with managing different TMS assets. The steps include the following:

- Identify as many challenges as possible.

- Develop if/then statements for each identified challenge. For example: "If no vendor competitors exist for this product, then the agency may lose any leverage for cost controls."

- Conduct an analysis to examine the likelihood and possible impact of the challenge defined in each developed statement by asking questions such as the following:

  - What are the impacts of this challenge to the agency?
  - What are the impacts of this challenge to travelers?
  - What is within the control of the agency and what is not?
  - What is the priority of the asset at risk from this challenge?

- Use the analysis results to prioritize the challenges to manage. Considerations may include whether the agency can manage the challenge; the priority of the TMS asset, including both normal operations and emergency operations; the cost and level of effort; and the likelihood of the challenge occurring.

- Develop a plan that identifies mitigation and management strategies for prioritized challenges.

In interviews with State agencies, the research team learned that agencies recognize these unique challenges. However, because these challenges are unpredictable, agencies often do not have a specific means for planning for them or addressing them to proactively manage different assets. A typical agency approach is to factor these challenges into the potential failure rates of the assets, where feasible. For example, an agency may track the number of failures of an asset as a result of factors such as lightning or precipitation and then estimate the likely number of required replacements.

Data on the condition of TMS assets provides an opportunity for agencies to better understand the challenges to consider with monitoring and managing these assets in response to a range of different scenarios. By documenting data over the assets' lives, including inspection, asset status and other maintenance data, agencies can synthesize the potential impact of different types of challenges. This information may be used similarly to condition information to determine whether specific assets need different environmental protection, where to locate assets, and how to allocate resources, such as whether to invest in an asset where the potential for threats may outweigh the potential benefits.

TMS ASSET CONDITION PRACTICES

This section provides a summary of practices an agency may consider in assessing condition:

- **Consider previous experience.** This experience may include understanding how environment or parts availability may impact condition. In addition, as Caltrans documented, condition may be based on a single element of a TMS asset.[25]

- **Consider the quality and availability data.** Agencies benefit from using accurate and available data to assess condition. Available data may not provide the most complete condition assessment but allow for assessments that are consistent and possible given resource constraints.

- **Define condition to support managing TMS assets.** Agencies benefit from defining conditions in ways that clearly explain the health of TMS assets to stakeholders. While models exist to define condition of TMS assets as “Good,” “Fair,” and “Poor,” agencies may benefit from determining condition ratings that support managing the assets and that align with asset prioritization and classification.

- **Identify challenges and opportunities for TMS assets.** Agencies benefit from preparing for potential challenges, which first require identifying those challenges. Broad stakeholder collaboration can help to identify the distinct types of threats and the risks they pose. As an example, Wyoming DOT regularly convenes its maintenance group to identify common or frequent challenges like environmental issues.[2] Prioritizing challenges for mitigation or management can leverage the classification and prioritization of assets as discussed in the asset classification chapter. For example, a TMS asset in a mountainous area may be at higher risk for environmental threats, but that risk is weighed against the priority of the asset in terms of maintenance strategy.

[2]Wyoming DOT interview, “TMS Asset Management Interview,” conducted by Matt Weatherford, February 2019.

CHAPTER 7. TMS ASSET DATA MAINTENANCE

OVERVIEW

This chapter describes the activities and resources agencies may need for maintaining the data on TMS assets over the assets' lifecycles. TMS asset data maintenance comprises the activities, practices, and resources to continually update and improve the asset data.

Because cost data accumulates for an asset over each asset's life, this chapter also provides an overview of the sources of TMS asset costs, including those for operations, maintenance, and replacement as well as a summary of lifecycle cost analysis (LCCA).

The following describes the relationship of the information in this chapter to TAM, as summarized in chapter 1.

> **FHWA TAMP Element: Summary Listing of Assets (23 CFR 515.9(b)-(c) and (d)(3))**
>
> The objective of data maintenance activities is to ensure that data are kept up to date and accurate over the life of the TMS assets, resulting in an accurate summary listing of the TMS assets.
>
> **FHWA TAMP Element: Lifecycle Planning (23 CFR 515.7(b))**
>
> LCCA provides information on estimating the costs for managing TMS assets over their lives, including understanding how costs may change as the condition of the assets change.

The topics covered by this chapter include the following:

- The purpose of maintaining TMS asset data.
- Practices to ensure the data quality and accessibility for maintaining data over asset lifecycles.
- Sources of cost information and practices for estimating those costs over asset lifecycles.
- Cost analysis practices to assess LCCA applicable to managing TMS assets.

Data maintenance relies on the foundation established in previous chapters regarding what data are useful and the tools to manage the data. Data maintenance is also important in ensuring that condition can be accurately assessed, which is discussed in chapter 6, TMS Asset Condition. Condition is dependent upon the current state and history of an asset, which means agencies rely on data to be updated over the asset lifecycle. This chapter addresses data governance, which describes the policies and procedures associated with ensuring data quality within an organization, including consistency over an asset lifecycle.

Because cost data on assets changes over time as maintenance is performed, TMS asset cost data are also discussed, including the sources of cost data from procurement through operations. The discussion covers how this data may be collected and maintained to reflect the true costs of assets and the value of accurate cost data in managing TMS assets.

The discussion provides a context for how TMS asset data supports spare management resources as discussed in chapter 8, TMS Asset Spares and Support Resources. Accurate and updated information is reliable information upon which to forecast spare needs and to track an agency's spares and available resources for maintenance and repairs. For example, poor asset data maintenance could result in a spare being placed into service but not reported as being taken out of the inventory. This chapter also aligns with how an agency manages asset changes and configuration as discussed in chapter 9, TMS Asset and Resource Configuration. Data governance provides practices for documenting how and when assets are changed and documenting the history of an asset's configuration.

TMS ASSET DATA MAINTENANCE

Asset data maintenance comprises the activities, practices, and resources to continually update and improve the asset data. This chapter focuses on the purposes of TMS asset data maintenance in terms of managing TMS assets, the data to be maintained, and some typical resources that support updated and improved asset information.

Purposes of TMS Asset Data Maintenance

The purpose of TMS asset data maintenance is primarily to ensure data quality that will provide an accurate view of an agency's assets, their conditions, performance, and needs.

- Historical data provides information about assets over their lifetime that can be used to analyze the assets. The historical analysis may include measuring lifespan of asset types, determining lifecycle costs, and performance.

- Current data provides information about the asset's present performance, condition, status, configuration.

TMS Asset Data to Maintain

In short, all TMS asset data that is managed also needs to be maintained. Chapter 4, TMS Asset Inventory, discussed inventory and identified profile attributes that typically do not change over the lifecycle of an asset, such as make and model, specifications, and yr of deployment. Although these data are perceived as static, they still require maintenance because changes, though infrequent, can happen. Those changes include software and firmware updates that change specifications, updates to warranties or asset documentation, and the retirement of an asset, at which time it can no longer be actively managed. Upon retirement, the asset's data only has historical value.

Many asset attributes require more active maintenance. Data that changes can include information about the asset status, condition, configuration and even location if an asset is portable or moved. Not maintaining data may result in an agency performing analysis and making assumptions based on information that is no longer valid or does not reflect the current state.

TMS Asset Data Maintenance Resources

Chapter 5, TMS ADM, discussed the sources and practices for gathering asset data from various sources and managing the quality of that data. Maintained data are expected to change over the lifecycle of the asset. Sources may include:

- Construction plans and as-builts that indicate when assets are moved.
- Contracting documents that capture the costs of replacement, spares, and other costs incurred by assets over their lifecycles.
- Monitoring tools that continually collect data on the assets, providing updated data that can be stored in data management tools and used for analysis. Examples may include asset status, failures, and failure modes.
- Derived data, such as condition, that changes throughout the lifecycle based on criteria such as age, maintenance, and performance. Agencies benefit from tools that can automatically update derived data.
- Maintenance activities to support data maintenance. Inspections and work orders document the maintenance history of an asset over its lifetime and changes in an asset's configuration. Maintenance activities, when integrated into data management, support an agency having current data about its assets.

MAINTAINING ASSET DATA OVER ITS LIFECYCLE

This section highlights the importance of maintaining asset data from procurement through retirement. Data itself has become an important asset for agencies that is collected, stored, and maintained from its acquisition through archiving or disposal.

TMS asset data, in support of decisionmaking, is based on consistent, complete, and quality data across the enterprise. Data management, as discussed in chapter 5, may support the procedures for the data curation activities, while data governance, as discussed in this chapter, addresses the agency's roles, responsibilities, policies, and rules that govern the management practices. As previously stated, data governance is "high-level planning and control over data management."(27) Data governance helps industries control and manage their data enterprises.

Data Governance

The FHWA Data Governance Advisory Council definition of data governance is:

> *"[T]he discipline that establishes the criteria and requirements for data; their quality, management, policies, business process; and risk management for handling of data within FHWA. In short, it is a corporate approach to collecting and managing data."*(28)

This definition divides data governance into three major categories: people, processes, and rules of engagement. Many DOTs are developing data governance policies for their critical data, and these policies apply to TMS asset data governance policies; managing the integrity and quality of assets is one of the priority reasons for initiating data governance. Data-governance initiatives, according to a peer review exchange, are divided into the following areas:

- **People** includes describing data management roles and responsibilities, establishing a data-governance organization, and identifying leadership. As examples, Maryland DOT set up an asset management office, and Florida DOT established the Reliable, Organized, Accurate, Data Sharing (ROADS) program.(11)
- **Processes** includes describing and formalizing data quality and management with reporting requirements (e.g., metadata, data curation plans). For example, Minnesota DOT established data steward policies and require data curation plans for each dataset.(21)
- **Rules of Engagement** consists of rules related to curation, validation, collection/maintenance, security and access, etc. These rules provide crosscutting data management principles, tools, and rules for decisionmaking. For example, Minnesota DOT data-stewardship policies describe rules for how data stewards collect, store, and provide access to datasets.(21)

Data governance, when linked to asset inventory and management, formalizes their practices and policies to ensure sustainability and process improvement over the management of asset information and the management of the asset lifecycle. Or, as a common maxim states: "If you can't measure it, you can't manage it."

Data governance ensures that cost and lifecycle information collected over time is of consistent quality—clean, organized, and complete; the information can be integrated and made accessible to end users, and the data can apply to similar "state of good repair" analysis over time without changes to the process.

In decentralized organizations where several divisions or regions collect information, data governance is even more important to ensure the collection and processing of consistent, timely, and accurate asset information. Differences in grouping assets into different asset types, identifiers, or attributes will impact the centralized authority from assessing the status of the device. For example, whether the collection of sensors that comprise the RWIS are inserted individually or as a group will alter the number of RWIS versus the number of road temperature sensors. Agencies can establish data-governance policies that direct data stewards or asset managers to use the same parameters and curation activities to support consistency and completeness through their data management responsibilities.

Data-Governance Framework

A complete framework for data governance includes data roles and responsibilities; data policies such as privacy, sharing and security; rules for data integrity; consistency and interoperability; and organizational accountability. The Florida DOT's ROADS data-governance initiative, as shown in figure 10, includes a simplified framework organized around the following: (29)

- **People**—Roles and responsibilities that ensure accountability from the operational, tactical, strategic, and executive levels. The operational and tactical staff are typically data stewards and custodians who manage the day-to-day operations of the data. ENTERPRISE data management teams or senior level managements oversee the data steward and help set consistent policies. Finally, champions are part of the executive levels, enforce the policies and support resources to manage the data.

- **Processes**—Training Florida DOT staff on the standard rules and procedures that support best practices as described by the Data Management Book of Knowledge (DMBOK).

- **Technology**—Adopting standardized tools, technologies that are used to make data and information more accessible.

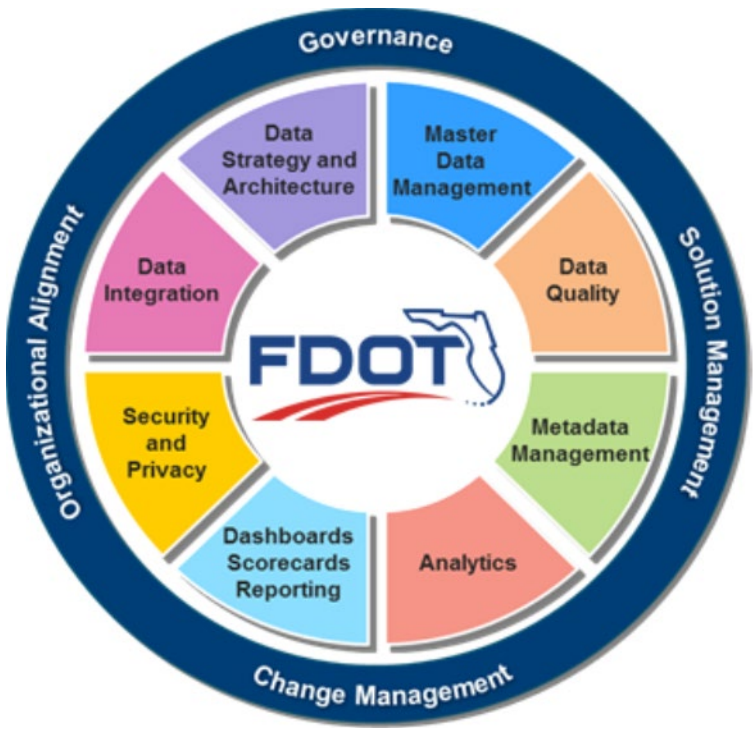


Figure 10. Diagram. Image of the Florida DOT ROADS initiative logo.

The ROADS framework implemented several basic initiatives:

- **Applications and reporting inventory**—A listing of internal/external applications and other information assets used across the agency.

- **Data-governance checklist**—A quick-reference guide for data-governance considerations in transportation technology projects.

- **Data governance roles**—Common position-description language for the enterprise data steward, data steward, and data custodian roles and responsibilities.
- **Data management handbook**—A data management tool based on the data lifecycle and providing additional documentation for each phase, such as metadata templates.
- **Enterprise business glossary**—A listing that defines key terms and definitions for agencywide use.
- **Enterprise data management**—An agencywide process that defines key considerations and provides related resources for each phase of the data lifecycle.
- **Technology process proposal**—A comprehensive process for evaluating promising technology projects.

Florida DOT crafted the initiatives through personnel assignments and internal projects to build the framework. Elements of the framework, inventory, checklist, handbook, and glossary, implement the data management best practices.

Data-Governance and Configuration Management

Configuration management is the practice of systematically handling changes so that a system maintains its integrity over time and is closely related to data governance and data management, which is discussed in detail in chapter 9, TMS Asset and Resource Configuration. Part of the governance process is to develop configuration management practices—the who, when, what, and how of applying configuration management processes—and who is responsible for ensuring the integrity and accuracy of those processes. Further, configuration management practices can be integrated into maintenance activities such that changes made to assets are documented and both history and current composition of assets are recorded. These practices would then be included in the curation plans implemented by data stewards.

TMS Operations and Asset Data Lifecycle Management

TMS operations tools can aid in collecting and managing TMS assets and their related performance data. As mentioned in the previous Asset Data in Maintenance section, the asset inventory can collect and store information on asset status, asset history and lineage, asset maintenance history, and asset operational performance. In addition, the asset inventory can include information on firmware updates, interface protocols and specifications, and current dataset uploads.

The importance of keeping track of asset information can be demonstrated by the following incident example: A truck could damage a gantry for a sign over the roadway that includes a dynamic message sign (owned by one region). A road sensor (owned by a second region) and a HAR (operated by a third region) are installed on the gantry. Owners of all impacted assets would need to be contacted about verifying and removing the assets prior to replacing the damaged gantry.

Further, when TMS software is updated, impacts can occur on downstream field sensors and devices that are included in the TMS asset inventory. The inventory can help assess the assets that require routine maintenance to update versions of software, interfaces, and datasets, which necessitates identifying the assets that are controlled by or support different stakeholders.

Managing TMS Assets Within an Agency's IT Enterprise Portfolio

As mentioned in chapter 5, TMS ADM, an agency's tools to manage TMS asset data are just a few among an agency's many systems. An agency's tools may interact with the GIS, pavement and bridge inventory tools, and other tools managed by a State or region. The data management system may provide access to construction management, enterprise resource planning (ERP), and safety management systems in an organization. In addition, different entities may collect and manage asset data both within and outside of the transportation organization. Key considerations related to managing and sharing information in an enterprise setting include:

- **Interface specification and dataset types—**An agency can establish standards that formalize interface specifications and formats so that the information is discoverable and complies with industry standards. These standards will mitigate impacts when adding, updating, or changing dependent or sharing systems.

- **Enterprise data dictionary—**An agency can establish a data dictionary of information that is shared across systems. The dictionary can include road classes, asset type names, identifier conventions, location referencing systems and methods, etc.

- **Crosscutting staff expertise—**Agencies may benefit from training staff to operate multiple family of tools to enhance integration development activities. Cross-training staff will also provide additional backup when primary staff are not available or on leave.

- **Collaboration among system administrators—**Agencies may facilitate discussion and collaboration among toolset system administrators so they can share experiences and concerns and can collaboratively solve problems.

TMS ASSET COST DATA

This section provides an overview of how TMS asset costs are determined over the asset lifecycle, including costs for operations, maintenance, and replacement. The objective of this section is to provide insight into practices to utilize asset data to accurately capture the asset costs at each asset level.

By documenting and maintaining data on the cost sources, an agency may be better able to estimate future capital costs. An agency may find value in integrating cost data into its TMS asset data tools to identify and assess the asset attributes that may impact costs, such as location and environment of asset, make and model, quantity procured, availability of utilities, communications, and infrastructure.

TMS Asset Capital Costs

Capital costs are those associated with fixed, one-time expenses incurred on the procurement and deployment of an asset. Capital costs are useful to an agency to help understand the amount of money invested, estimate replacement cost, measure the cost-benefit of assets, and determine the current value of assets as they degrade over time.

Data on capital costs may be contained in contracts, particularly if the contracts breakdown costs to include different cost sources, such as:

- TMS equipment costs.
- Associated infrastructure costs (e.g., poles, mounts, and cabinets).
- Costs of installation, configuration, and calibration.
- Associated costs of software and software licenses.
- Costs of warranty and technical support.

TMS Asset Operations and Maintenance Costs

The Operation and Maintenance (O&M) costs of an asset are the sum of the costs associated with operating and maintaining that component. Typical examples of these costs for TMS assets include the associated costs of utilities and communications. Operations costs may also include recurring costs such as for license renewals and for assets or their devices that are provided as services to an agency.

TMS asset maintenance costs may include routine and preventive maintenance performed periodically, asset repairs and the replacement of components or devices, and the physical and cybersecurity maintenance costs associated with protecting the asset and its information.

Factors in Operations and Maintenance Costs

Agencies derive costs from the data they collect, which may include estimates by a manufacturer, contracted costs, and the historical maintenance costs for similar assets. Factors that may impact the cost of an asset inventory include:

- **Make and model**—Costs and routine maintenance requirements may vary by the unique specifications of a make and model of the same asset type. For example, pan/tilt/zoom cameras may have more complex mechanisms than regular ones.

- **Location**—Costs may vary by geography. For example, a rural district may require greater travel costs for getting to and from assets, while an urban district may have higher costs associated with traffic control. Similarly, different districts may have different maintenance contracts with third parties. The Nevada DOT model allows for a different maintenance cost table for each district.[30]

- **Asset Classification**—Georgia DOT's maintenance contract provides incentives for the rapid repair of assets classified as 'vital," which are the highest priority.[31] This classification may result in higher costs for these repairs but supports a higher level of availability for the vital assets.

- **Performance history**—The performance may vary by asset or elements. Different deterioration rates in performance may result in different maintenance types, which leads to different lifecycle costs.

- **Condition** – As discussed in chapter 6, TMS Asset Condition, Nevada DOT estimates maintenance needs based on the condition of assets, incrementally increasing the maintenance needs and associated costs as the condition deteriorates (i.e., the asset ages).

Maintaining Cost Data

Costs are dependent upon accurate data. To ensure data quality and reliability, agencies may manage cost data in the same way that they manage other TMS asset data and maintain it through appropriate data governance from reliable cost sources. Cost sources may include project management systems, maintenance management systems, work order systems and project and funding plans.

An agency will find value in securely interfacing systems containing cost data with the tools used to manage asset data. Chapter 5, TMS ADM, provides more information on practices for securely interfacing data systems to ensure accurate authoritative data.

The tools may require modification to include all cost sources that an agency deems relevant. For example, Washington State DOT's data management tool was originally designed for traffic signals but has been expanded over the yr to include TMS asset data and to track costs and maintenance efforts at the asset level.[1] This cost information by asset can be used in estimating future maintenance costs and identifying assets with higher than usual maintenance costs.

TMS LCCA

This section provides a summary LCCA applicable to TMS assets by describing LCCA and the resources that support it, including the challenges and gaps often experienced by DOTs when developing LCCA for TMS assets. The chapter also provides examples of DOT practices that illustrate effective LCCA.

TMS Asset Deterioration Rates and Maintenance Types

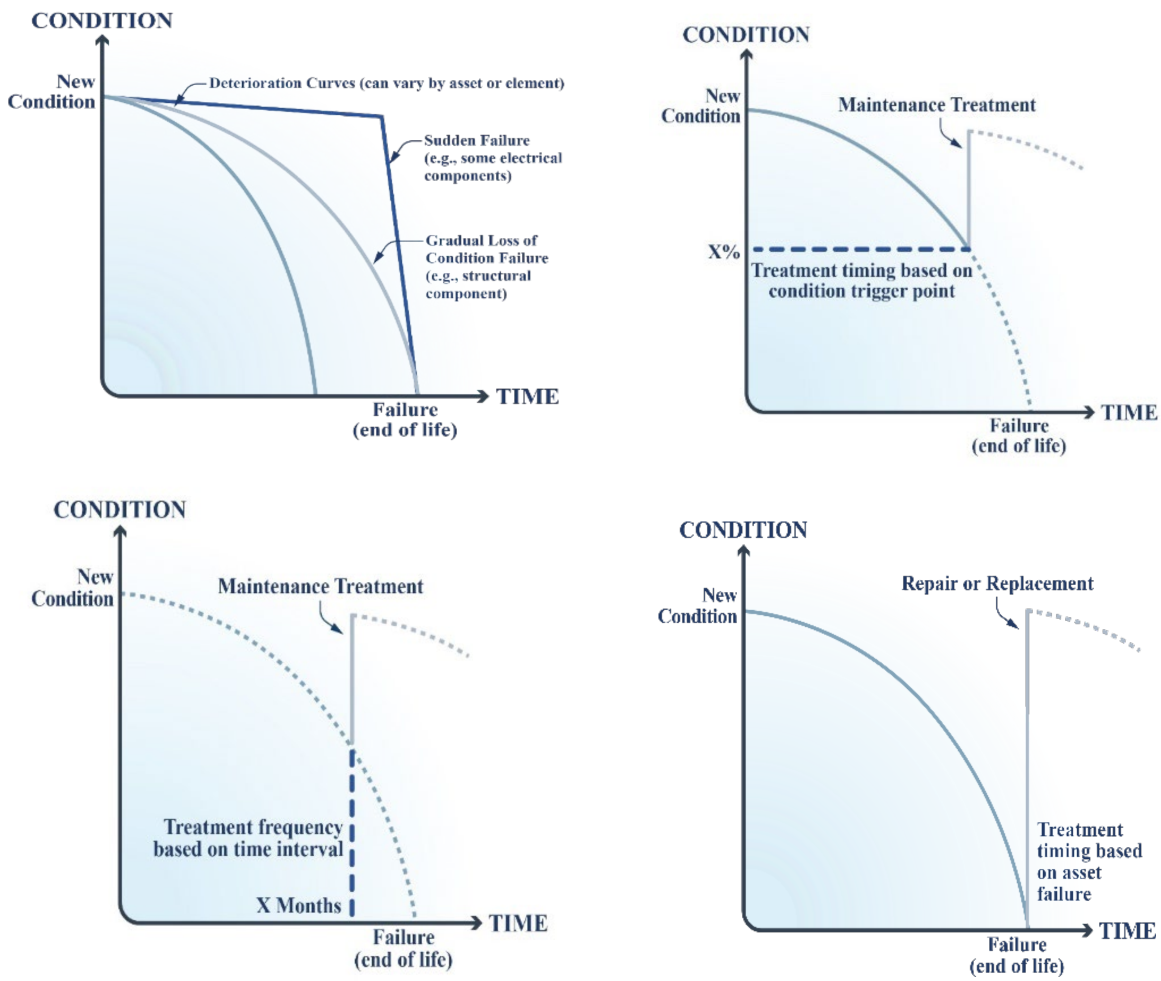
TMS assets will eventually reach a point of failure, and this timeframe is often referred to as the life expectancy. Each asset will deteriorate at a different rate. Figure 11 illustrates deterioration rates for a TMS asset and its components. The maintenance approach for each TMS asset type may differ, depending on its risks and effect on the transportation network. The common maintenance management types are:

- Condition-based maintenance management.

[1]Washington State DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, November 15, 2020.

- Interval-based maintenance management.
- Reactive maintenance management.

Figure 11 shows various maintenance approaches, while the graph in the upper left also shows different asset deterioration curves or rates. Deterioration rates are relevant to TMS assets because, as previously discussed, TMS assets may fail or degrade in different ways than traditional transportation assets. Starting from a new condition, the TMS asset may experience gradual degradation (at various rates as shown) for its structural elements or sudden failure for its electrical elements. The deterioration rate can vary by asset or even the components and the devices that comprise it.



Source: FHWA.

Figure 11. Chart. Varying asset deterioration and maintenance approaches.[(32)]

The lifecycle performance of the TMS asset may behave differently depending on the level of maintenance the agency implements. Condition-based maintenance is scheduled based on regularly monitored performance and is typically used for assets with long lifecycles. Interval-based maintenance is scheduled at specific periods based on an analysis of asset performance. This approach is used for assets with either short or long lifecycles. Reactive maintenance management is performed in response to reported asset failures or events that require repair or replacement to return the asset to service.

For a technology or ITS component, an agency follows an interval-based approach. Information on the age, expected useful life, and recommended cycles of preventive maintenance and replacement for ITS assets is used to develop a maintenance management model that generates needs information. Investment activities for ITS assets include repair and replacement required to restore a damaged or deteriorated asset to standard design, functionality, and capability.

TMS Asset LCCA

Traditional LCCA allows for calculating the lifecycle cost of a transportation asset by summing up the monetary equivalency of all agency costs (e.g., construction and maintenance costs) and use or social costs (e.g., costs associated with congestion and crashes) throughout the analysis period. However, due to the differences between traditional transportation assets and emerging technology-driven TMS, the traditional LCCA process for roadway infrastructure assets may be refined or modified for TMS asset management.

The differences between the components of TMS and those of bridges and pavements are related to degradation characteristics, maintenance strategies, inflation behavior, consideration of uncertainty, dependency, risks in terms of technical obsolescence, and the need for a proactive inventory management strategy.

In addition, for evaluation of system effectiveness and estimating time to failure, TMS assets tends to have similarities with the IT industry. Besides the traditional LCCA considerations, TMS assets' reliability, availability, maintainability, and capability (RAMC) may be considered in the new TMS LCCA framework to address the trade-off between lifecycle costs and system performance considering RAMC. Adoption of the LCCA methodology for such systems with stochastic treatments of high uncertainty components is critical to establish a practical LCCA framework for TMS lifecycle management planning and cost analysis.

Florida DOT has developed a LCCA spreadsheet that provides the following output:

- The expected lifecycle costs by subgroup and DOT district to meet the performance targets established by the agency.
- Expected performance given the existing funding. Because funding is limited, the expected performance is less than the agency's targets.
- The impact of changes in how funding is allocated on performance, such as providing more funding for inspection, or more funding to address the highest priority assets.

By estimating various cost scenarios, Florida DOT can determine funding and performance gaps and make decisions about how to best spend limited funding.[2]

[2]Florida DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, October 28, 2020.

Figure 12 provides a conceptual framework for ITS LCCA. This framework identifies the direct costs of acquisition, maintenance and replacement, and the indirect costs in terms of reduced performance and their impact on travelers as factors to consider in determining the appropriate level of investment. Agencies need to collect, manage, and maintain accurate cost data for their analyses to be accurate.

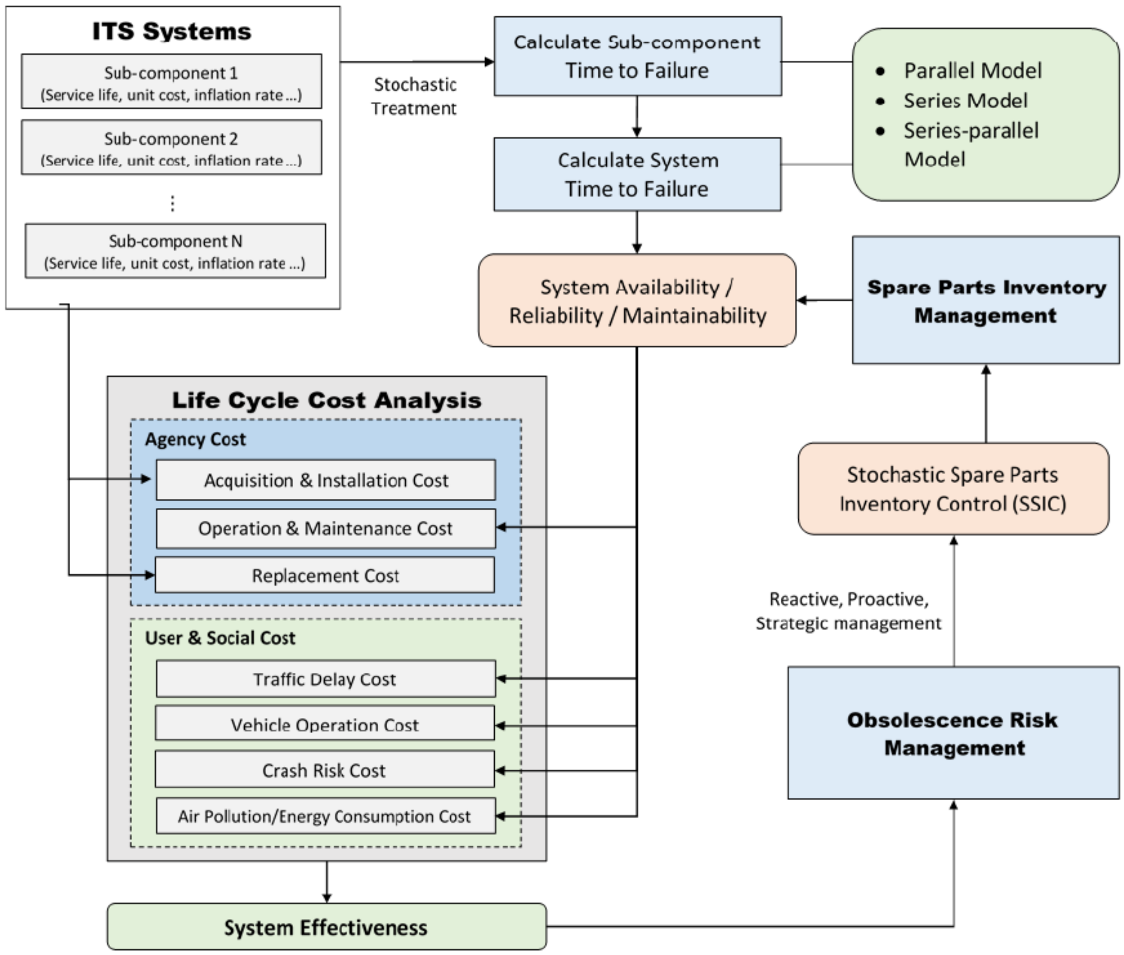


Figure 12. Diagram. Proposed conceptual LCCA framework for ITS.[(33)]

TMS Asset LCCA Challenges

The key challenges for LCCA for TMS assets include but are not limited to:

- Identifying the attributes for the relevant components and sub-component of a TMS, such as service life, unit and system costs, and other unique features. This challenge requires ensuring that data can be collected, managed, and maintained regarding these attributes and that data management tools are available to perform analysis using the data.

- Determining proper inflation rates for technologies used in TMS subsystems, components, and devices. The inflation in technology can differ from the Consumer Price Index. In many cases, a technology decreases in actual cost over time. However, the technology may also be superseded by other technologies that provide more functionality or performance but also cost more.

- Determining the current condition, remaining useful life, and/or time to failure for TMS subsystems and components and the entire TMS. As discussed in chapter 5, TMS ADM, agencies may find that accurately determine the condition of TMS assets and to predict when they will fail is challenging.

- Determining the impact of agency, user, and social costs in the proposed TMS LCCA framework. While this chapter discusses TMS costs, the framework also relies on accurately estimating the impact TMS assets on traffic operations, in particular the cost in delay, damage, and environmental impact resulting.

TMS ASSET DATA MAINTENANCE PRACTICES

This section describes practices an agency may consider for improving its maintenance of TMS asset data and its TMS asset cost estimating, including:

- **Identify existing data-governance initiatives and policies that are applicable to TMS asset data**. The maintenance of TMS assets relies on good data governance. As previously discussed, for State agencies, the data are often collected at the regional level, with each region prioritizing the effort differently. Accordingly, establishing schedules and processes for data collection and making TMS practitioners understand the importance of updating data in a timely manner supports having consistent and reliable data for performing analysis and making decisions.

- **Treat data as an asset with a TMSs lifecycle.** Agencies benefit from having the resources and activities to not only collect and store data but to maintain it over the TMS's lifecycle. This practice includes identifying the data that will be updated, determining what will happen to data that does not represent the current state, and disposing of data that no longer has value.

- **Identify data maintenance roles and responsibilities.** As with data management, agencies benefit from establishing the roles and responsibilities of stakeholders in maintaining data. The responsibilities may include sharing updated data in a timely manner, ensuring there is data access, and having activities in place to identify new data that needs to be shared with data management tools.

- **Consider lifecycle costs during planning and procurement.** The following example from the Georgia DOT illustrates how lifecycle costs may be planned for and, to some level, controlled.

Example: Georgia DOT TMS Asset Data Maintenance[3]

Georgia DOT does not formally estimate lifespan or perform LCCA but has developed an innovative approach to contain costs of its TMS. Maintenance for the TMS is performed by a contractor who is tasked with achieving performance targets for different asset types as discussed in chapter 3.

Georgia DOT conducted an SE process using the comprehensive data it has collected over the last 10 yr to develop a request for proposals that provided potential contractors with the information needed to determine what the cost would be and what resources would be required to meet the DOT's performance targets for TMS assets statewide. The contract provides incentives to potential contractors to prioritize assets the way Georgia DOT has classified them, with "vital" assets requiring the highest level of availability.

The contract includes tools that allow Georgia DOT to continue monitoring its assets and collect data for its next maintenance procurement process. This process was labor intensive during SE but is the result of rigorous data collection, management, and maintenance and has provided Georgia DOT relative certainty in the annual costs of its TMS.

[3]Georgia DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, November 2, 2020.

CHAPTER 8. TMS ASSET SPARES AND SUPPORT RESOURCES

OVERVIEW

This chapter discusses the importance of managing the spares and support resources that may be needed for TMS assets to meet their performance targets. Spares are extra components and devices kept in inventory to replace parts that have either failed in use or have been identified as needing replacement as part of preventive maintenance activities. Replaceable means that the spares can be acquired and be swapped for a part that is in use.

Spares can maintain or improve the performance and condition of assets. For example, in an automobile, spare parts could include spark plugs and filters, which can be replaced when degraded (e.g., reached end of expected use) or failed to restore or maintain vehicle performance. Examples of spares for TMS assets may include modems in field devices or logic boards for CMSs. A spare part may also be a component, such as a complete CMS, when an agency cannot acquire devices or when replacing devices will not result in a satisfactory repair.

The following describes the relationship of the information in this chapter to TAM, as summarized in chapter 1.

> **FHWA TAMP element: Summary Listing of Assets (23 CFR 515.9(b)-(c) and (d)(3))**
>
> An agency benefits from inventorying them as they do assets to understand the availability, location, and usability of its spares, just as it does its assets.
>
> **FHWA TAMP Element: Asset Management Objectives (23 CFR 515.9(d)(1))**
>
> Spares, either to repair or replace assets, are an important element of an agency's ability to maintain the performance and extend the life of its assets. Specifically, spares support maintaining an asset in good repair over its lifecycle at minimum practicable cost.

The TMS Asset Spares and Support Resources chapter builds upon the previous discussion in chapter 3, TMS Asset Identification and Classification. Asset identification and classification provides insight into an agency's TMS assets and their priority and therefore the importance of having the appropriate spares to support their continued operation. Discussions in chapter 4, TMS Asset Inventory, help an agency understand the assets it owns and the replaceability of asset components and the devices of which they are composed. Note also that spare parts are part of an agency's TMS asset inventory and may be managed using the same data management activities and resources as other TMS assets. Chapter 5, TMS ADM, covers how to track spare parts supplies and their use and helps determine when additional spare parts are needed.

The discussion in this chapter is relevant to chapter 9, TMS Asset and Resource Configuration. The use of spare parts or devices may be documented and tracked through configuration management activities to support an agency's understanding of the composition of its TMS assets and how they change over time.

SPARES IDENTIFICATION

In an ideal world, all TMS assets would be readily repairable or replaceable. Unfortunately, the real world presents many obstacles to TMS asset maintenance, one of which is identifying what can and cannot be repaired. The purpose of this section is to discuss the issues to consider in identifying the spare parts for TMS assets that support their operations at the desired performance levels.

Chapter 3, TMS Asset Identification and Classification, provides an overview of how agencies may identify and classify their TMS assets, while chapter 4, TMS Asset Inventory, discusses the inventory data an agency may collect on those assets. Identification and classification help an agency define at which level an asset is repairable. The inventory may include details such as make, model, and specifications that can be used to determine whether suitable replacements are available, including different makes and models with comparable functionality. Inventory may also provide insight into how often components and their devices need replacement using, for example, manufacturer guidance on life expectancy or maintenance instructions that identify which parts of an asset may wear out over time.

In identifying spares that an agency may want to have available, the agency may consider if and how an asset can be repaired. The composition of TMS assets vary, and components and their devices may be easily replaced, or be integrated into an asset such that the replacement of parts can be a complex maintenance activity or a risky activity that compromises the integrity or performance of the asset. Maintenance staff can provide insight, potentially through capturing their experiences in ADM tools, on effective repairs.

For example, a HAR may be composed of several parts that include an antenna, power unit, logic unit, and a modem. If each of these parts can be easily swapped, an agency might have spares for each part that is likely to need replacement. However, if the parts of the HAR are integrated or contained in a sealed unit, an agency may identify the complete unit as the spare.

Another consideration in identifying the potential need for and possible number of spares is whether the parts can be replaced in the field or will require removal and offsite repair at a maintenance facility or by the manufacturer. When a part requires offsite repair, an agency may consider having "cores." A core is an inoperable asset that can be repaired. Repairs to the cores can be made offsite, and then the repaired core is available as a spare that can be swapped in the field. When a repaired core is put into operation, the inoperable but repairable asset it replaces can then become a new core to be repaired offsite.

The following factors influence availability of spares:

- Whether spares are still manufactured or available. In the case that a spare is no longer being manufactured but stock is still available, an agency may consider stockpiling the available parts.

- Whether spares are cost effective and support a state of good repair at minimum practicable cost. A spare part might be too expensive to justify purchasing it to repair or replace an asset.

- Whether spares can be procured in a timely manner. Some parts may be rare or have high demand for a limited quantity. Or, a spare may be unique to an asset, and while a vendor can still supply spares, the part may require significant lead time for the vendor to manufacture.

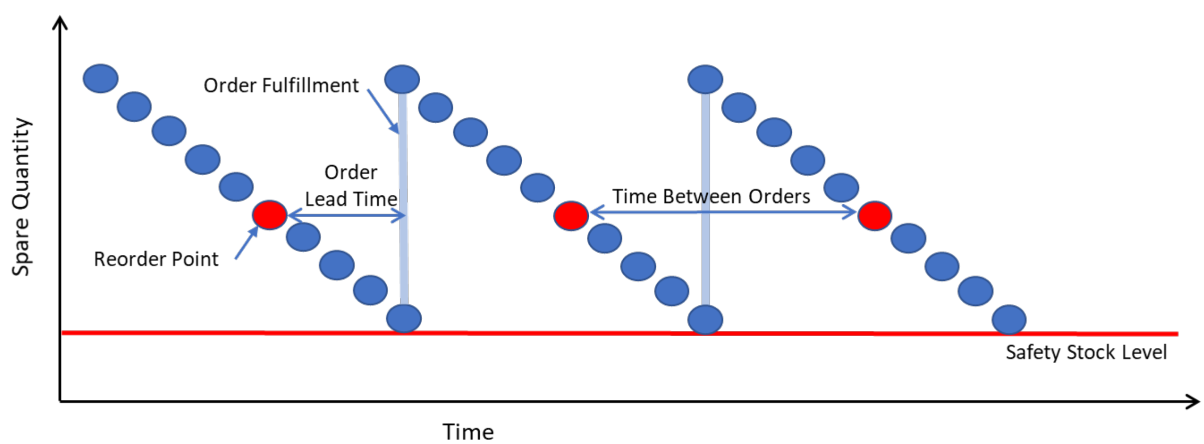
- Whether interchangeable spares are available, meaning that functionally equivalent parts, potentially from a different manufacturer, can be used as spares.

The issue of spare availability can be addressed through the SE process. Specifically, in assessing the needs for a TMS asset during planning, an agency will consider how long a system will need to operate and then develop requirements that describe expectations for interchangeability and availability of parts over that entire lifespan. This assessment may result in a procurement that requires a vendor to guarantee spare parts availability and that TMS assets use interchangeable parts where feasible.

SPARES FORECASTING

The section discusses how agencies may forecast spares quantities to support having the appropriate quantities available. Having spares in stock or immediately available is typically more efficient than ordering them when needed, due to the time needed to procure and receive spares. In other words, having parts on hand may require less resources and paperwork.

However, having large inventories of spares in stock can be inefficient because they represent funds that may be better allocated elsewhere, and an agency risks their spares becoming obsolete or damaged while in stock. The sawtooth diagram shown in figure 13 provides an overview of a means for forecasting spares quantities and needs.[34]



Source: FHWA.

Figure 13. Chart. Sawtooth diagram for forecasting spares.

In the sawtooth diagram in figure 13, each dot represents a spare. The Y-axis shows the total spare quantity an agency has available. As the spares are put into service over time (the X-axis) the agency's spare quantity decreases.

Agencies may estimate the quantity of spares needed based on the rate at which the spares are put into service. For example, an agency with 300 traffic cameras and an average replacement rate of 10 percent per yr may target a maximum spare quantity of 50, which is the 30 an agency will replace in a yr plus a minimum safety stock level of 20, as represented by the horizontal line.

The safety stock level represents the minimum quantity of spares the agency believes is acceptable. An agency may determine the safety stock level by estimating the spares that needed in a worst-case scenario, such as catastrophic or widespread failure, or the sudden discontinuation of a part. Another consideration may be having sufficient spares distributed over a wide geographic area, such as having spares in multiple districts or warehouses in a State. In the traffic camera example, the agency may have a safety stock level of 20 for the agency.

Order lead time is the expected time between an agency initiating an order for spares and those spares being available to the agency. Order lead time may include the time required for agency requisitions, approvals, purchase orders, and order fulfillment by the vendor, which is illustrated as the increases in spare quantity in the diagram.

The sawtooth diagram illustrates that timely new orders are initiated to allow for fulfillment before the agency reaches its safety stock level. In the camera example, if the order lead time for spares is 6 mo, and the agency uses 30 spare cameras per yr, a 4-mo order lead time suggests a reorder should be initiated when the spare quantity is safety stock level (20) plus 10 mo' of replacements on average.

The camera example is simplified, and an agency may have many variables that affect its spare forecasting, including those reflected in the following questions:

- **What are the priorities of the assets?** Agencies may use the priority of an asset in classifying them. For example, Georgia DOT staff said that it has classified assets in three categories: vital; essential; and general. Each classification has a defined minimum level of uptime required. The vital classification is the highest level and may result in a higher spare quantity in relation to failure rate because the agency requires those assets to be available 97 percent of the time, meaning a greater expectation for them to be repaired quickly.[21]

- **How does the need for spares align with funding and procurement processes?** While the sawtooth diagram suggests initiating orders based on order lead time and estimated time to reach safety stock level, an agency may order spares when funding is available. However, the size of orders may still be planned to ensure the spare quantity never drops below the safety stock level.

- **Can spares be delivered just-in-time?** Vendors and agencies may use just-in-time delivery where the vendor may stock the spares for agencies with the ability to deliver them quickly when needed. Just-in-time delivery may not eliminate the need for an agency to stock spares, but it may reduce the agency's safety stock level. This may help

[21]Georgia DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, November 2, 2020.

an agency preserve funds spent as advanced payments on spares, or from having large spare quantities on hand.

Chapter 5, TMS ADM, discusses the tools an agency uses to manage its asset data, and those tools may also be used for spares forecasting. Data management can provide information on the rate of replacement for different types of spares. As discussed in the next section, data management tools may be used to track spares alongside TMS assets.

SPARES INVENTORY

For an agency to maintain its TMS assets using spares, it will need to know what spares it has and that those spares are available and appropriate for the needed repairs or replacements. This section discusses how an agency may inventory its spares to accurately know their quantities, locations, condition, and applicability. For example, not all traffic cameras are the same. The inventory information for a traffic camera may include make, model, number, and yr of manufacture, which may be essential to know whether the spare is applicable in the needed situation because a vendor may change specifications over time.

A common and effective practice is for an agency to inventory its spares, which may be components or the devices of an asset, in the same way that it inventories its TMS assets. This process may include using the same tools and the same activities to track spares and update the inventory. Consistency in inventorying can result in having the same data at the same level for similar assets, components, and the devices comprising them. Even though inventory data may be similar, the use of the data may vary, including the following considerations:

- Unlike TMS assets in operation, the condition of spares will typically not change until they are put into use. However, how long the agency has had a spare in stock is relevant to determining its warranty status and identifying if a spare has been superseded by a newer part or if the spares an agency owns are no longer supported by their manufacturer. Some spares may never be used, but their cost may be considered a form of insurance against not having spares when needed.

- Some spares may be applicable for more than one type of TMS asset. For example, the same modems and other communications hardware may be used for several different types of field assets. An agency will benefit from mapping these spares to their many applications for TMS assets.

- While the locations of many TMS assets are fixed, spares are typically portable. By tracking the locations of its spares, an agency may assess and determine if they are in the most appropriate locations. If an agency determines an imbalance where, for example, one district has too many spares and another has too few, it can move the spares.

- Inventorying spares alongside the TMS assets supports configuration management, as discussed in chapter 9, TMS Asset and Resource Configuration. Inventorying spares makes the information available for configuration management processes and supports keeping up-to-date information on the composition and history of the TMS assets. For example, during the configuration process, an agency may identify that a part has been superseded and document the current and obsolete part numbers for future reference.

- Some spare parts may be made in small runs by vendors, and agencies may consider this fact in the quantity and timing of orders, regardless of immediate need.

Spares Storage

The objective of managing spares storage is to have its spares in the right place and the right condition for an agency's needs. Agencies may choose to store their own spares or have them stored by a third party, such as a contractor or vendor.

As previously discussed, an agency storing its own spares offers the advantage of quick access to the spares and the potential to store spares close to where they will be needed. However, spares require storage space and, in some cases, special storage conditions. Because of the technological nature of TMS assets, some components are fragile and may require protection from breakage or damage or require climate-controlled environments that prevent components from experiencing moisture, dirt, or extreme temperatures. An agency may need storage facilities that are appropriate for the spares. Also, agencies will want to know that the spares are secure and properly inventoried. Data management supports an agency's consistent tracking of spares across multiple locations.

As an alternative, contractors or vendors may store spares for an agency. In Georgia, a maintenance contractor is responsible for spares and is required to keep assets such as CMS and cameras operating at a defined level of availability. The contractor stores the spares it forecasts will be needed. This also leaves the contractor responsible for providing proper storage. Contractor or vendor storage can be defined during procurement, in which case agencies will develop detailed requirements that define spares availability expectations, including incentives or penalties for meeting or failing to meet the requirements.

As previously discussed, just-in-time delivery from vendors can support an agency having fewer spares on hand, resulting in fewer spares to be stored. Just-in-time delivery means a vendor may be able to quickly deliver the product to the agency when needed. Storage before just-in-time delivery to the agency is the responsibility of the vendor, and warranty periods would not start until the spare is delivered. Just-in-time delivery can be required and contracted in the procurement process. Note that a vendor may require an agency to contract for the delivery of a minimum number of spares.

SPARES MANAGEMENT RESOURCES

To perform effective spares management, an agency may not require new tools or significant changes to its business processes. Instead, agencies may review existing resources for managing TMS assets and identify how to utilize these resources for spares management:

- Data management tools, such as homegrown and commercial asset management applications, that may already have the capability to track spares inventory. Using the same tools for spares and operations assets simplifies linking those spares to the assets where they may be used. Workers supporting the storage and use of the spares use tools to track spares inventory and analyze stock levels, using rates and the distribution of spares.

- Maintenance tracking and work order tools, which may be integrated with other data management tools, are used by maintenance to document their work. The tools can help maintenance staff learn the location and availability of spares and document when spares are deployed.

- The planning, approach for procuring, and implementing tasks may define requirements for asset functionality and interchangeability that potentially allow for the use of more spares. Agencies may benefit from procuring assets with swappable components and devices, where feasible. During the SE process, an agency can also define requirements for the continued supply of spares, storage of spares, and just-in-time delivery.

- Configuration management provides a means for documenting the configuration of TMS assets, including changes to the assets, such as the swapping of parts. By documenting what changes were made and when, an agency may have the data to analyze the impact on performance or reliability effected by using spares.

SPARES MANAGEMENT PRACTICES

This section summarizes the discussion in this chapter to briefly describe practices an agency may consider to support effective spares management:

- **Identify a safety stock level for frequently needed spares**. In considering the safety stock level, consider where those spares will be located, procurement timelines, and spares' availability.

- **Begin planning for access to spares during TMS asset procurement.** Agencies benefit from considering the repairability of an asset and the potential need for spares during the planning for new TMS. The TMS program-planning process is where spares management starts. The long-term viability of TMS assets will benefit when their long-term maintenance and health are considered in the planning and design of systems.

  Georgia DOT has addressed many spares management considerations through a maintenance contract.[31] The contract details performance requirements and provides incentives for meeting performance goals that leaves the determination of spare inventory and availability to the contractor. The contractor is incentivized to meet performance targets and ensure they have adequate spares or have access to them.

- **Manage data on spares in the same way the TMS asset data are managed**. Agencies benefit from collecting and storing data on spares similarly to other TMS assets and then using data management tools to analyze their need for spares and the appropriate quantities of available spares. An example is when an agency uses the data management tool to identify the inventory that is in use (e.g., currently in the field), the spares that are available, and the assets to which they can be used for repair or replacement.

- **Consider the storage of spares and the value of options such as just-in-time delivery.** For spares that are too valuable or fragile for an agency to store, agencies may consider just-in-time delivery or storage by a contractor or vendor. This approach may increase the unit cost of spares for the agency but may also result in more certainty that spares will be available and are undamaged.

CHAPTER 9. TMS ASSET AND RESOURCE CONFIGURATION

OVERVIEW

This chapter discusses the role of configuration management in the managing of TMS assets. Configuration management supports maintaining systems, such as TMS assets, in a desired state. Configuration management is also a method of ensuring that systems perform in a manner consistent with expectations over time. In terms of managing TMS assets, configuration management provides a systematic approach to identify and document changes to assets, such as changes in what components and devices the assets are comprised so that an agency can develop realistic expectations of how those changes may impact performance and condition.

The following describes the relationship of the information in this chapter to TAM, as summarized in chapter 1.

> **FHWA TAMP Element: Summary Listing of Assets (23 CFR 515.9(b)-(c) and (d)(3))**
>
> Configuration management supports the accurate documentation of an agency's assets, including how the assets have changed over time.
>
> **FHWA TAMP Element: Performance Gap Identification (23 CFR 515.7(a) and 515.9(d)(4))**
>
> Configuration management may provide insight into the gaps between the desired and actual performance of TMS assets. Through configuration management, an agency is able to identify changes to assets and how changes may create gaps, which in turn supports the ability to decide where improvements may be needed.

Configuration management relates to previous discussions in this report, and its practices can be integrated with those of other activities to manage TMS assets. Configuration Management builds upon chapter 5, TMS ADM, through the systematic documentation of changes. Configuration management processes that are integrated into data management can provide valuable information for evaluating asset condition and performance, particularly how changes to assets may affect them.

Chapter 7, TMS Asset Data Maintenance, supports configuration by documenting changes made to TMS assets. That documentation can be incorporated into maintenance activities such that changes to assets are automatically recorded. Consistent documentation of changes provides a history for TMS assets, which can help an agency later in evaluating and monitoring its assets to identify the potential impact of changes on the condition or performance of an asset.

Configuration management and spare management can be closely related. Using spares to repair and replace TMS assets may be documented as changes to the configuration of the assets. Also, the documentation of deploying spares during maintenance provides information to track spares inventory.

CONFIGURATION MANAGEMENT

The Configuration Management for Transportation Management Systems Handbook states that "configuration management programs and plans provide the technical and administrative direction to the development and implementation of the procedures, functions, services, tools, processes, and resources that are required for the successful development and support of a system."[22]

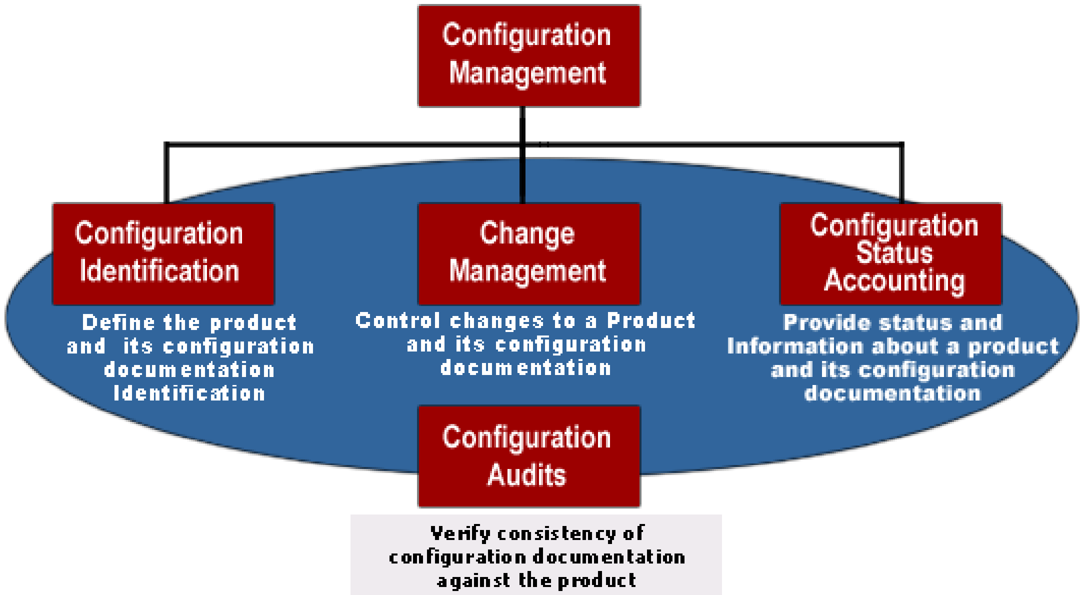
Configuration management systematically handles changes so that a system maintains its integrity over time. It involves the policies, procedures, techniques, and tools to:

- Document proposed changes, including the resources required and the expected outcomes so that changes may be evaluated and managed.
- Track the status of changes from proposal through implementation and determine the impact of the changes.
- Maintain an accurate inventory of assets and their supporting documentation as changes are implemented.

Configuration management supports:

- Comprehensive documentation of changes made to TMS assets over their lifetimes, including what is changed and when, why, and who made the changes.
- Preserving records of the history of previous asset configurations.
- Monitoring and tracking of the condition of the TMS assets.
- Documenting asset metadata, as discussed in chapter 5, TMS ADM.

Figure 14 shows a high-level illustration of the configuration management process. The illustration is followed by a discussion of the elements of the process as relevant to TMS assets. Note that more information on the process can be found in *The Configuration Management for Transportation Management Systems Handbook*.[22]



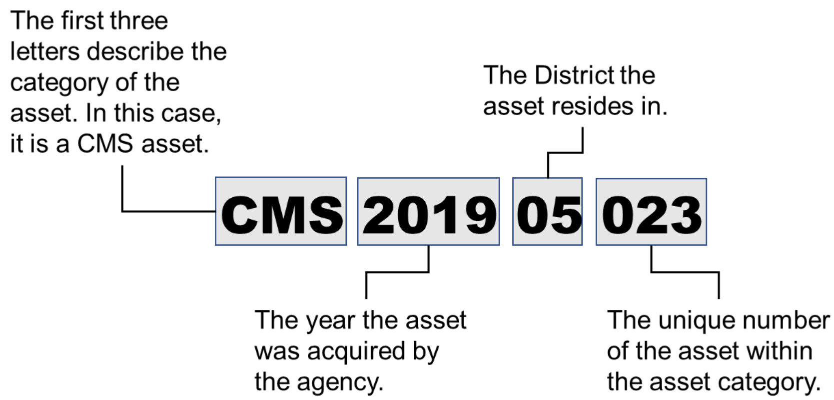
Source: FHWA.

Figure 14. Diagram. Configuration management process.(22)

Configuration Identification

Configuration management starts with identifying the equipment that falls within the change control process. For TMS, this equipment may include the TMS assets that an agency identifies to be managed, as discussed in chapter 3, TMS Asset Identification and Classification. Once the assets within change control are identified, an agency determines the information needed to describe them for configuration management purposes.

The information needed to describe an asset may be captured in a unique identifier for each asset. For example, an agency may use an identification structure that results in the unique identification (ID) "CMS201905023" for a CMS). Figure 15 shows how the example CMS201905023 is structured to provide information about the item identified.



Source: FHWA.

Figure 15. Diagram. Unique asset identification composition.

Here, the asset will be referenced as CMS201905023 across multiple data tools, such as for maintenance, GIS, ATMS, and asset management tools. This identifier supports the ability to relate the asset inventory information across tools and for different groups within an agency to have a mutual understanding of what and where each asset is.

The data an agency uses to uniquely identify each asset may vary by agency, but the Asset ID is always unique for each asset. The example that follows shows how Georgia DOT's NaviGAtor generates unique identifiers.(31)

***Example: Georgia NaviGAtor Asset Identification*(31)**

Georgia DOT has a system to uniquely identify each asset in NaviGAtor via information that includes the following:

- A prefix code to identify the item type for a class.
- A code to identify the item as a document, hardware, software, etc.
- A unique number for that asset among all items of that type.

The configuration identifier is a small subset of the information an agency may have recorded in its asset inventory because the purpose of configuration identification is to uniquely identify each item for tracking. More detailed inventory data may be available elsewhere, such as in TMS ADM tools, and this data can be accessed by querying the unique identifier.

Configuration identification is most effective when it starts at procurement. Establishing a unique identifier at the moment an agency owns a device supports consistency in referencing and collecting data for the asset.

Change Management

Also known as change control, this process assesses the impact of a change to a system, determines the fate of the proposed change, executes approved changes, and ensures that the change is carried through following the proper documentation. During this process, an agency may identify potential performance gaps resulting from changes. An agency may then determine whether and how to address those gaps to ensure performance targets are met.

The Kansas Information Technology Office (KITO) provides an example of a change management and control process. KITO has a configuration management policy for major technology projects, such as its 2021 procurement of a new ATMS, that includes a change management form.(35)

Example: KITO Change Management(35)

The KITO must approve the change management form prepared by the Change Control Board prior to making changes to major technology projects. The Change Management Form includes:

- Project information.
- Description of the proposed change.
- The type of change, such as systemic, organizational, or procedural.
- Justification for the proposed change.
- The impact of not implementing the change.
- At least one alternative approach to the proposed change and the potential impact of the alternative.
- The configuration items affected by the proposed change.
- Impact on cost, schedule, and resources.
- Approval or rejection of the proposed change and the reasons for approval or rejection.
- Dates for the proposal, acceptance, or rejection.

While each Kansas agency may have a different process and different documentation, the KITO form represents a consistent process to capture important change information. It provides guidance to project teams on the considerations for proposing changes, including what may happen if the change is not enacted and the estimated impacts.

The form uniformly applies to all major technology projects for Kansas, and provides a paper trail required by policy, which documents a history of changes to technology assets. That history can be reviewed later to determine if changes provided the expected impact.

The information in the change management form is valuable for TMS asset data because it documents any changes, the expectations, and when the changes occurred. This information can help an agency assess and establish its performance targets. The information may also be useful for maintenance to understand the configuration of the asset, asset maintenance requirements, and any needed spares.

Configuration Status Accounting (CSA)

CSA is the process that ensures the relevant information about a TMS asset—documentation and change history—is current and has the necessary information. Typically, CSA involves establishing and maintaining documentation for the entire lifecycle of an object. The primary benefit of CSA is that it provides a methodology for updating all relevant documentation to ensure that the most current configuration is available. CSA ensures that accurate data are recorded on assets over their lifecycles so that the data may be used in analysis of the impact of changes on performance and lifecycle of assets.

For TMS assets, CSA is related to TMS asset data quality and data governance. Many TMS assets consist of swappable components and devices, and replacement may impact the performance and the expected lifespan of the asset. Data management can ensure the ability to collect and store accurate configuration status, while data-governance policies can support CSA by identifying the asset data to be maintained.

For TMS assets, CSA is also related to spares management. CSA can ensure accurate tracking of spare inventory and provide an understanding of where spares have been deployed and how they have changed the configuration of assets.

Configuration Verification and Audit

In this part of configuration management, agencies analyze configuration items and their respective documentation to ensure that the documentation reflects the current state. While change control ensures that any change is implemented in an orderly and controlled way, configuration audits verify that the changes identified were appropriately implemented.

When a field device such as a camera fails, the priority of an agency may be to repair or replace the item as quickly as possible to restore operations, with no emphasis on documenting the changes enacted, such as the replacement of hardware, to repair the device. Subsequent maintenance activities, such as inspections, may include verification that assets are as expected, including as per any documented changes. Through the agencywide use of unique asset identifiers, the configuration of assets as observed during maintenance can be compared to asset inventory and change control data. Inconsistencies between what is observed and what is expected can be discovered, which then may be addressed to bring assets and their inventory data up-to-date, as well as to explain performance gaps.

A **configuration management plan** (not shown in figure 14), serves to define how an agency will perform configuration management. The plan is related to and may document the data-governance framework for TMS asset data.

A configuration management plan may already exist within an agency as developed for other assets. In managing TMS assets, an agency may benefit from knowing whether a plan exists and understanding how asset data are managed or governed by that plan and whether TMS asset configuration can be managed consistent with it. The plan also provides information on the tools and resources that already exist and that may support managing TMS assets.

A plan typically addresses the following:

- Personnel.
- Administrative bodies.
- Activities.

- Items under configuration management, which may include TMS assets.
- Policies.
- Configuration management tool descriptions.

Note that some agencies may not have a configuration management plan but may have formally or informally implemented some of the configuration management plan processes without identifying them as configuration management.

Agencies without formal configuration management may believe that they do not have a sufficient baseline since they have not consistently documented TMS assets from their initial deployments. However, a plan can identify existing practices that may be incorporated into configuration management with little disruption. In other words, disciplined practices to manage TMS assets can serve as a basis for configuration management. The activities for managing TMS assets and their data can be used to document the configuration of existing assets going forward and for new assets through their entire lifecycle.

Because configuration management is closely related to managing TMS assets, the formalization of activities to manage a TMS asset management program may present an ideal time to also establish configuration management and identify the synergies that can benefit both.

CONFIGURATION MANAGEMENT IN TMS PLANS AND PROCESSES

This section provides a summary of how configuration management results in reliable data that can be used in TMS plans and processes:

- **TMS Planning and Feasibility Studies** rely on accurate TMS assets inventory data, including quantities, locations, and conditions. As discussed previously in this chapter, configuration management processes support controlling and recording changes made to TMS assets, which provides an agency with a better understanding of the condition and expected performance of those assets.

- **TMS Programming, Resource Allocation, and Day-to-Day Operations** represent processes that can be integrated into configuration management, as discussed in CSA and configuration auditing and verification. Operations and maintenance are activities where an agency may document the proposed and enacted changes for its TMS assets. Changes may be small, such as upgrading a cellular modem on a remote camera to work on a newer cellular network (e.g., fifth generation (5G) cellular). However, that change may be valuable for identifying which assets will still need to be changed when older cellular networks (e.g., third generation (3G) cellular) are no longer supported by service providers. Similarly, documenting software configurations can help an agency understand its security vulnerabilities when vendors stop providing patches or updates to older software.

- **TMS Procurement, Project Development, and Implementation** benefits from configuration management performed over the lifetime of a TMS asset. The configuration and changes to an asset are recorded from procurement to retirement. This record provides insight into the most effective asset configurations and maintenance activities that include changes and ensures an accurate accounting of the baseline of TMS assets as assets are procured and documented.

- **TMS Evaluating, Monitoring, and Reporting** benefits from knowing how TMS assets have changed over time so that those changes can be monitored and evaluated to determine the impact on performance. Changing a cellular modem for a remote camera may result in access to a stronger cellular network and the ability to capture higher-resolution images or more frequent images. However, other changes may weaken the performance of an asset, and that information is useful later in evaluating whether the change was worthwhile.

CONFIGURATION MANAGEMENT PRACTICES

This section summarizes the practices that an agency may consider in integrating configuration management into managing TMS assets:

- **Identify existing configuration management plans and activities.** Agencies may already have plans and activities that define the expectations and processes for configuration management, and TMS assets may be included in those plans. The plans and processes may include resources and tools to support TMS asset configuration management.

- **Start managing a TMS asset configuration at the beginning of its lifecycle.** TMS asset baseline data provides a foundation upon which all change and configuration data can be built. Management starts with uniquely identifying each asset at procurement and using unique identifiers consistently. Other baseline data, such as make and model, performance expectations, and the composition of the procured asset, provide a way to understand the asset as it exists and allows an agency to document the history of changes to the asset.

  TMS practitioners will benefit from discovering existing documented configuration management processes and aligning with them as practicable. Similarly, practitioners may identify and familiarize themselves with an agency's resources and configuration-management expertise to support TMS configuration management. Doing so can prevent a duplication of effort or developing processes that contradict those already established.

- **Plan for managing configuration with the TMS ADM tools.** Managing the configuration and changes to TMS assets may be integrated into the data management tools and activities discussed in chapter 5, TMS ADM. Data management can be aligned with change control and configuration management processes to uniquely identify assets, track inventory, and document when and how assets are changed.

- **Manage metadata to support change management.** Metadata provides an agency with valuable information on change and may include who, when, and why changes were made.

- **Capture change as part of data maintenance.** Change control and management are living processes, not just a paperwork exercise to record change. Agencies benefit from using data management tools to make change information available to stakeholders in TMS planning and processes. To maximize the value of change control data, an agency can make the data available to the stakeholders.

CHAPTER 10. MONITORING, EVALUATING, AND REPORTING ON TMS ASSETS

OVERVIEW

This chapter discusses the role of monitoring, evaluating, and reporting in managing TMS assets.

The following describes the relationship of the information in this chapter to TAM, as summarized in chapter 1.

FHWA TAMP Element: Lifecycle Planning (23 CFR 515.7(b)

As shown in this chapter, reporting can provide a means for reliable understanding the needs of TMS assets and estimating the cost of managing them.

FHWA TAMP Element: Measures and Targets for Asset Condition (23 CFR 515.9(d)(2))

This chapter described activities to evaluate and report on the performance and condition of TMS assets and compare that to an agency's targets. An agency may also evaluate the performance and condition of its assets to establish realistic targets for future performance and lifespan.

FHWA TAMP Element: Performance Gap Identification (23 CFR 515.7(a) and 515.9(d)(4))

The activities of this chapter are directly related to identifying gaps between expectations and the actual performance and condition of assets. Monitoring, evaluating, and reporting may be used to identify and report on the gap, and to provide information for TMS plans and processes to address those gaps.

The TMS asset management activities and outcomes associated with monitoring, evaluating, and reporting inform other TMS plans and processes, as illustrated in figure 2. By managing their TMS assets, agencies generate reliable and accurate information that informs its monitoring, evaluation, and reporting processes, leading to more informed decisionmaking.

By monitoring assets, an agency gains real-time information about the status of assets, which can be used to determine assets' ability to provide needed functionality and to help identify maintenance needs. Evaluation assesses the data collected from monitoring alongside other asset data as described in previous chapters to provide an agency with information on how the assets are performing compared to performance targets and to assess condition and performance. Reporting is effectively sharing information to different stakeholders about the TMS assets that help them make decisions.

The content of this chapter builds upon chapter 5, TMS ADM, and chapter 6, TMS Asset Condition, by examining how monitoring and evaluation can use and provide data from the practices and tools of data management to understand the condition and performance of TMS assets. This chapter also directly relates to chapter 7, TMS Asset Data Maintenance, as the monitoring and evaluation of TMS assets may be significant factors in determining the maintenance needs of TMS assets. Reporting utilizes the data an agency collects and manages about its TMS assets and relies on the data being accurate, accessible, and appropriate for an agency's information needs.

MONITORING TMS ASSETS

Monitoring is the practice of observing the status of an asset over time. Traditional transportation assets such as bridges or roadways may be monitored through annual inspections that identify structural weaknesses or worsening conditions. Periodic monitoring of infrastructure assets is appropriate because degradation is typically gradual. TMS assets, however, are complex systems that can fail suddenly, degrade rapidly, or stop functioning because of a single element failing, such as a modem or microprocessor. Their failures are often less predictable and can be catastrophic. Many IT professionals can recall times when they were woken in the middle of the night to address an unexpected computer failure that impacted multiple other systems with which it interfaced. As a result, TMS assets justify a different monitoring approach than that for other transportation assets. The differences include:

- Using remote tools for monitoring.
- Monitoring at a high frequency (e.g., multiple times per minute).
- Monitoring of multiple elements of an asset.
- Monitoring of IT elements, including communications, hardware, and software.

Monitoring TMS assets may take the form of in-person and remote observations. An example of in-person observation is a maintenance inspection process that can be used to examine the asset components and devices and identify any physical issues, such as frayed wires, overheating, or corrosion from moisture. As discussed in chapter 9, TMS Asset and Resource Configuration, maintenance inspections may also be used to audit asset configuration and verify that the system is composed of the expected components and devices.

Agencies can perform remote observation using software tools that allow for observing field assets. Remote observation may verify that the asset is operational and functioning as expected, such as verifying that the message sent to a CMS is displayed as expected. Remote monitoring may include monitoring the communications network to verify that field TMS are powered on and sending/receiving data. Remote monitoring also may be performed using existing tools, such as the TMS software that communicates with field devices regarding their health and performance.

When monitoring TMS assets, an agency determines:

- The available data that provide insight into the status of the asset.
- The appropriate level of detail of data needed to adequately monitor TMS assets.
- The frequency and level of detail for monitoring based on the asset classification.

Consequently, monitoring TMS assets supports maintaining the data for these assets. Monitoring provides consistent data on status and performance that can be used to update the TMS asset inventory. Examples of data that an agency can maintained through monitoring include status, performance metrics, and location for mobile assets. Whether conducted remotely or in-person, data that is collected through monitoring informs agency decisions about performance expectations and for maintaining existing assets, including maintenance schedules and inventory of spares.

Table 12 provides an example of attributes for sign type assets and the frequency of their collection from *FHWA-HOP-20-025: Performance Measures and Health Index of Intelligent Transportation Systems Assets.*[36]

Table 12. Asset attribute collection frequency for a CMS.[36]

Asset Attributes	Collection Frequency
Device up/down availability	Once every 5 min
Over temperature alarms	Once every 5 min
Humidity alarms	Once every 5 min
Pixel/lamp errors	Once every 5 min
Power errors	Once every 5 min
Communication errors	Once every 5 min
Fan alarms	Once every 5 min

Monitoring for availability, errors, and alarms can identify issues that may be responded to according to the classification of the assets. For example, a CMS that is classified as a tier 1 asset may need a more immediate maintenance response than a tier 3 remote HAR that is used seasonally.

Who Performs Monitoring?

Monitoring may be done by practitioners with daily interaction with TMSs, such as the following groups:

- Operators in TMS operations centers who control traffic cameras and CMS or use data collected from traffic detectors in managing traffic. The status and condition of a TMS directly impacts how they do their jobs. A CMS or camera that cannot be controlled may impact how an operator responds when a crash occurs on the highway near the asset's location.

- Staff that manage communications networks who may monitor network communications and identify whether assets are available and how quickly the assets are able to respond to queries. This information may be shared with operators in real time and may also be collected to help assess asset condition.

- Maintenance staff who physically observe assets when doing inspections and repairs. They may observe issues, such as damage to devices. While the condition of TMS assets cannot always be determined by observation. However, immediate physical needs may be.

Monitoring Tools and Resources

Chapter 5, Traffic Management Systems ADM, discusses tools and resources to manage TMS asset data. The following are examples of how agencies currently monitor their TMS assets.

- Georgia DOT's ITS IAMS is a tool built specifically to manage assets that can communicate with field devices.[(31)] The tool provides a dashboard that shows the assets geographically along with their status, such as whether they are online or not and how long an asset has been down. The tool also shows assets that are down and the status of any maintenance work planned for the asset. The dashboard also aggregates monitoring data for evaluation and reporting purposes.

- As previously discussed, many agencies use their TMS software and operators to monitor the status and performance of field assets, including alarms and notifications when assets lose communication or faults are detected. The software may share status information with other systems or may aggregate it for evaluation and reporting purposes.

- Network monitoring software can detect the status of the communications network and the devices on it. While the software may not provide specific details about TMS device performance, such as whether the data communicated is accurate or timely, the software provides a more holistic view that can reveal factors on a network that impact device functionality and performance, such as overall network traffic, traffic at nodes, and the failure of network hardware.

- Agencies also collect and analyze status information via spreadsheets, maintenance management systems, and customized databases. These tools can be used to collect information about the status of TMS assets and document maintenance activities related to the assets. For example, an agency can use the maintenance system to record changes to an asset as part of configuration management activities. Status information, when related to change information, can provide insight into the impact of the changes on the performance of the asset.

EVALUATING TMS ASSETS

Agencies evaluate TMS assets to assess their performance and condition. Chapter 6, TMS Asset Condition, discusses condition in more detail and describes practices that support how agencies use condition in managing TMS assets. Specifically, evaluation may drive decisions about performance expectations, maintenance, replacement, and retirement. This section provides information on practices, tools, and resources for evaluating TMS assets.

Evaluating Performance

Evaluating the performance of TMS assets compares the actual performance of assets against expectations. Effective evaluation requires establishing performance measures for an asset and accurate data to compare results to the measures. Accurate data are the product of an inventory defined with evaluation in mind and by effective data management practices.

Considerations an agency may have in selecting performance measures include the following:

- **Are the measures appropriate for the asset classification?** Measures should be commensurate with the priority and classification of an asset, with higher priority assets typically expected to have higher performance targets. For example, an agency may expect its higher priority assets to have less downtime than its lower priority assets.

- **Are the measures linked to the agency's overall performance goals?** Measures with a clear link to agency goals provide an understanding of why the measure is important and what the agency is expecting to achieve through the measured performance.

- **Can the measures be evaluated?** Quantifiable goals based on available data provide clear measures to evaluate actual asset performance. When defining inventory and asset attributes, an agency will consider what data are available, the level of effort in collecting it, and its value in evaluating the assets.

- **Are the measures understandable?** The measures provide the information to explain an asset's condition and performance to various audiences in terms that those audiences understand.

Evaluation Based on Monitoring Data

Monitoring TMS assets provides data points that can be used to inform agencies of their assets' current status, to provide information that can be acted upon for corrective actions, and to evaluate performance and condition. An agency may set performance measures that can be evaluated through data gathered from monitoring. For example, if a measure for an entire class of TMS assets is to be up more than 90 percent of the time, monitoring data over time may be used to compare actual performance against that target.

Performance Measures and Health Index of ITS Assets(36) provides examples of how information gathered from monitoring can be used to evaluate performance against established measures:

- **Asset health/uptime/reliability**—Reliability of each type of ITS equipment/system can be determined by calculating the amount of time the equipment/system was malfunctioning compared to the total amount of time the equipment/system is operational for each mo of the yr. Time operational is given as a percentage of hours during each mo that a particular system is functioning.

- **Mean time between failures**—This measure is the predicted elapsed time between inherent failures of a mechanical or electronic system during normal system operation. It can be calculated as the arithmetic mean (average) time between failures of an asset.

- **Mean time to repair**—This measure relates to the maintainability of repairable items. It represents the average time required to repair a failed component or device. Expressed mathematically, mean time to repair is the total corrective maintenance time for failures divided by the total number of corrective maintenance actions for failures during a period.

- **Malfunction/issue type**—When trouble tickets associated with a device malfunction or failure are created, recording the type of issue observed can be beneficial. For example, for a CMS, standard failure messages can be detected, including fan failure, pixel failure, over temperature alarm, etc. Knowing the frequency of different failure types can help understand which spares to stock, resulting in more quickly resolving issues.

A consideration when evaluating TMS assets is whether the evaluation aligns with what is observed through monitoring. Agencies may observe that asset conditions are not as expected or predicted and may choose to explore what other data and factors will improve the accuracy of their evaluations.

In addition, maintenance staff observation can be valuable and may be incorporated into evaluating assets. Maintenance staff should have a means to compare what they observe with what is expected and to document their observations within the tools the agency uses to manage TMS asset data.

Evaluating Condition

As discussed in chapter 6, TMS Asset Condition, agencies grade the condition of their assets in various ways. Some may strictly use asset age, and some may evaluate the performance of assets. The condition derived from evaluation may be used to:

- Estimate the asset value.
- Forecast the asset's needed level of preventive and corrective maintenance.
- Determine which assets to retire, replace or upgrade.

The following is an example from Nevada DOT of condition assessment based on asset age.

Example: Nevada DOT ITS Asset Condition Assessment

Nevada DOT has established the condition rating strategy for assets as shown in table 13.[(23)] The condition is evaluated by comparing the actual age of an asset with the manufacturer's recommended service life. The date an asset is put into service is recorded and then tracked against the manufacturer recommendation. The resulting condition is then used to support maintenance and replacement decisions.

Table 13. Nevada DOT ITS age-based asset condition evaluation.[(23)]

Condition	Age of Device
Good	Less than 80 percent of manufacturer's recommended service life
Low risk	Greater than 80 percent but less than 100 percent of manufacturer's recommended service life
Medium risk	Greater than 100 percent but less than 125 percent of manufacturer's recommended service life
High risk	Greater than 125 percentage of manufacturer's recommended service life

As discussed in chapter 5, TMS Asset Condition, agencies may also evaluate condition based on other measures, including those described previously in this section. An asset may be considered in good, fair, or poor condition based on its uptime or frequency of malfunctions. Other considerations in evaluating the condition of TMS assets include:

- **Repairability**—As spares become unavailable or increasingly difficult to obtain or software and firmware updates are no longer available, agencies may downgrade the condition of an asset. Similarly, the difficulty of repair and frequency of failure may combine to result in an asset's condition being rated as poor and in need of replacement. At Georgia DOT, an asset being considered no longer repairable is a factor in prioritizing the asset for retirement or replacement.[22]

- **Cost to maintain**—As assets age, costs to maintain may be expected to increase. This fact is partially reflected in age but may also be reflected in overall cost. As maintenance costs approach replacement costs, an agency may lower its condition rating to reflect the need and cost-effectiveness of replacement.

- **Obsolescence**—Despite age, technologies may become obsolete or be superseded by lower cost, more effective alternatives. An example is short-range wireless traffic detection, which agencies have retired before the end of the detectors' expected life because probe vehicle data may be less expensive to acquire and be more useful.

[22]Georgia DOT interview, "TMS Asset Management Interview," conducted by Jeremy Schroeder and Matt Weatherford, November 2, 2020.

Who Evaluates TMS Assets?

While practitioners who interact with TMS assets on a daily or frequent basis are monitoring the assets, planners or managers may evaluate these assets to understand how they are helping the agency meet its goals. While monitoring may be done at a component and device level in real or near real time, evaluation may take a longer-term view at a higher level. The results of evaluation may be used in reporting on TMS condition to support decisionmaking.

EVALUATION TOOLS AND RESOURCES

Evaluation capabilities may be incorporated into the software tools an agency uses to manage TMS asset data. Using data management software allows for evaluations to be consistent and based on accurate data. Business rules within the software can be established to evaluate the asset condition and performance against configured measures. As in Georgia, the software can also inform the software users when assets fall below established performance thresholds or are not working.(31)

Agencies like Nevada DOT and Florida DOT also use spreadsheets that "roll up" asset data statewide and regionally. The data are collected regionally and then aggregated to the statewide level. By aggregating condition across an entire asset class, agencies can evaluate the overall health of that class.

REPORTING ON TMS ASSETS

The purpose of this section is to discuss the role of reporting in sharing the appropriate information about TMS assets. Effective reporting incorporates the results of evaluating TMS assets and frames those results for presentation to different audiences.

Many practitioners who interact daily with TMS assets may be so familiar with them that reports are not necessary to describe the inventory and its health. However, other stakeholders may not have that familiarity and may be more results-oriented in how they view TMS functionality. For an agency's executive-level staff, TMS may be only one of many pieces of the transportation network for which they are responsible. Appropriate reporting to different stakeholders supports decisionmaking about future investment, use, and the composition of TMS assets in an agency. At a minimum, reporting on TMS assets can be used to:

- Describe the effectiveness of TMS in meeting agency goals to highlight strengths and weaknesses in current TMS practices.
- Describe TMS assets health and needs to support an understanding of the age and condition of assets.
- Support planning and budgeting, including expanding the use of TMS where doing so benefits an agency.
- Develop maintenance strategies by identifying how resources may be effectively allocated to preserve and improve existing TMS assets.

Reporting Audiences

Effective reporting is targeted and tailored for its audience and framed for that audience's needs and required level of detail. Each audience may need different types of information at different levels. This section provides examples of audience types and the information they may want. In addition to monitoring assets through tools such as dashboards and software, practitioners may want reports to provide an understanding of asset conditions and performance. The practitioner group may be the TMS and TSMO staff who rely on TMS assets to do their jobs. Practitioners may also be operations management who need to understand the role of specific assets in meeting performance targets. This group may be interested in more granular data about specific assets and asset types to support operations.

Example: Nevada DOT ITS Annual Costs Statewide[23]

Figure 16 shows a forecast of the costs to maintain the existing ITS assets in Nevada. The forecast is based on estimates of assets' maintenance needs according to their conditions, with aggregated data from the three districts in the State. Reporting information in this way is appropriate for decisionmakers who may need a cost figure to include in budget planning. This forecast may also provide insight for planning that assesses the benefit of TMS assets in relation to their costs.

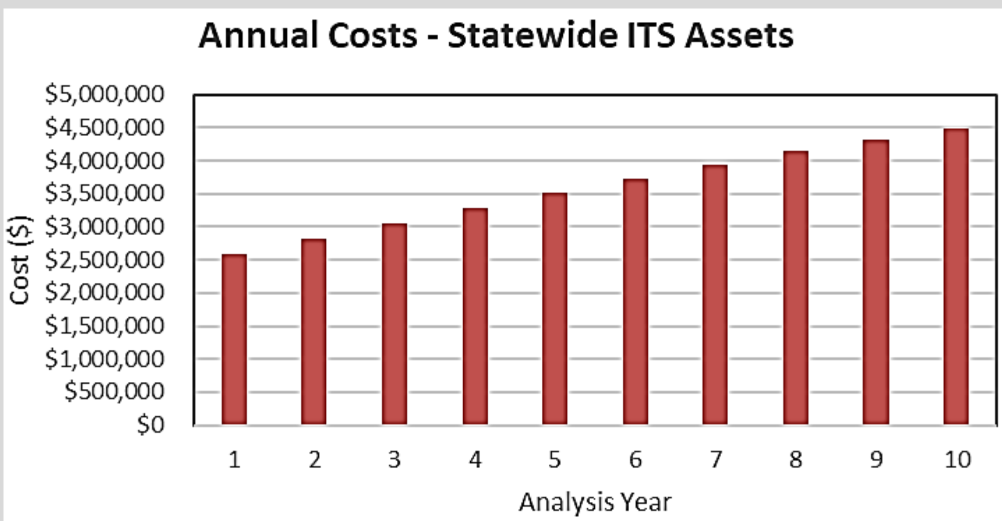


Figure 16. Chart. Nevada DOT ITS asset cost forecasting.[23]

Decisionmakers who may use the information in budgeting, planning and assessment will probably not be as interested in the condition of individual assets as they are in what is needed to meet the performance expectations. This group may be more interested in a high-level overview that gives them an analysis of their investment. The following example shows how Nevada DOT aggregates ITS asset information resulting in a cost estimate chart that may be appropriate to present budgetary needs based on condition to decisionmakers.

Elements of Effective Reporting

Reporting TMS asset information is effective when the information is understandable and presented consistently for audience expectations. For example, using a different condition rating system for TMS assets than what is used for other agency assets may be confusing and difficult for an audience to relate TMS asset needs to infrastructure needs. Effective reporting includes:

- Presenting information clearly by framing it in the context an audience is familiar with, and only presenting the information a specific audience needs.
- Using reliable information that results from good data management practices. Reliable information results in consistency over time and in more reliable reporting of the changes in inventory and condition.
- Reporting has a clear purpose, such as to show a need for additional funding or to demonstrate the effectiveness of TMS as an alternative to traditional transportation solutions.

Opportunities to Report on TMS Assets

TMS practitioners benefit from seeing TMS asset information presented in terms they are familiar with, but that presentation may not be consistent with how agencies report on other assets. Practitioners may not need TMS information to be consistent with how other assets are reported. For decisionmakers dealing with multiple asset types, consistency with how other assets are presented is essential.

An agency's TAMP is an opportunity to describe TMS assets, their conditions, and the investment in them alongside other transportation assets, such as bridges and roads. To be effectively presented in the TAMP, TMS asset information can be organized and presented in alignment with the eight elements of TAM described in the introductory chapter of this report.

Managing TMS assets can be an important strategy in a TSMO program. TSMO plans may report on the impact of asset condition on TSMO strategies. The plans may also show how changes in investment will affect condition and, consequently, performance. Documenting TMS assets in TSMO plans allows for investment decisions to be made at the TSMO planning level and alongside other TSMO priorities.

Other places where TMS asset information can be reported include long-range plans, regional investment plans, and State transportation improvement plans. The previous example from Nevada DOT provides dollar amounts that may be used as a line-item in State budgets for future yr.

TMS MONITORING, EVALUATING AND REPORTING PRACTICES

This section summarizes practices that an agency may consider in integrating configuration management to support managing TMS assets.

Monitoring Practices

- **Consider the tools and resources currently used to monitor TMS assets**. The practitioners who interact with the TMS assets daily benefit from having asset monitoring capabilities integrated into the tools they already use. For example, an operator in a control room may view camera images, traffic maps, computer-aided dispatch, and performance dashboards. Integrating monitoring capabilities into their existing tools may result in them being able to pay more attention to the status of the TMS assets. A TMS can provide alerts and alarms when an asset has a fault or notify TMC operators when an asset is no longer communicating.

- **Consider integrating monitoring activities into maintenance**. Integrating maintenance management with monitoring may help staff who generate work orders and track their progress toward restoring asset functionality identify issues. Georgia DOT's IAMS example in this chapter allows the ability to generate work orders.

Evaluating Practices

- **Ensure quality data to produce quality evaluation.** Evaluating TMS asset condition begins with consistent and accurate data. Developing good practices for the collection, governance, curation, and accessibility of data will result in quality data that supports reliable evaluation.

- **Establish activities to incorporate observations into managing the TMS assets**. Observation is an important element of evaluating TMS assets. Agencies may benefit from incorporating observation by maintenance staff or others to validate asset condition forecasts and assumptions. Observation can also provide validation and verification of asset configuration.

Reporting Practices

- **Define your audience and report at the audience's interest level.** When reporting on TMS assets, an agency benefits by understanding that one report may not fit all audiences. In developing asset management tools, an agency may consider the reporting needs of different audiences, from those who interact with TMS assets every day to those who need high-level information for budgeting and planning.

- **Report on TMS assets to be consistent with audience understanding**. Framing information about assets in the appropriate context supports the audience understanding what is being reported. As an example, for ITS asset management, Nevada DOT rates condition as good, low risk, medium risk, and high risk; they transform those to good, fair, and poor for reporting alongside other transportation assets.

APPENDIX A. RESOURCES FOR MANAGING TMS ASSETS

This appendix summarizes resources that this report draws on and that provide additional information on various aspects relevant to managing TMS assets. Agencies may consider reviewing these documents to support and augment the contents of this report as they plan to manage TMS assets.

Recognizing the value and importance of a broad range of asset types in transportation, FHWA has many available resources:

- *Handbook for Including Ancillary Assets in Transportation Asset Management Programs* (FHWA-HIF-19-068).(37) A methodology is presented to help practitioners determine what assets, other than pavements and bridges, are most important to support agency missions and goals. The methodology includes prioritization of asset classes and identification of data related to those assets for supporting a performance-based approach to managing the condition and utilization of those assets. The methodology is comprehensive, yet flexible, so it may be tailored for specific agency needs.

- *Applying Transportation Asset Management to Intelligent Transportation Systems Assets: A Primer* (FHWA-HOP-20-047).(32) This primer provides information for practitioners to apply TAM principles to ITS assets in accordance with the TAMP requirements. This primer is intended to help transportation agencies benefit from including ITS assets in their asset management planning and integrating asset management practices for ITS assets.

- *Applying Transportation Asset Management to Traffic Signals: A Primer* (FHWA-HOP-20-048).(14) This primer provides information for practitioners to apply TAM principles to traffic signals in accordance with the TAMP requirements. This primer is intended to help transportation agencies benefit from including traffic signals in their asset management planning and integrating asset management practices for traffic signal assets.

- Performance Measures and Health Index of Intelligent Transportation Systems Assets (FHWA-HOP-20-025) (pending publication).(36) This report synthesizes and identifies best practices in ITS asset management. Best practices include utilizing data from ITS assets to provide visualization and summary of that data to support ITS asset management and to advance TSMO capabilities and support integration of TSMO into the management and operations of the TMCs and agency's transportation system.

- *Transportation Management System Performance Monitoring, Evaluation, and Reporting—A Primer for Practitioners* (FHWA-HOP-07-123).(38) This primer contains an overview of TMS performance measurement and describes how to establish a performance measurement program.

- *Linking Performance and Asset Management* (FHWA-HIF-19-073).(73) This paper examines how the TAM, performance management processes, and planning requirements in the CFR increase the linkage between asset management and performance management.

- *Integrating Asset Management and Planning* (FHWA-HIF-19-074).[40] This paper examines how TAM, performance management, and performance-based planning and programming are likely to increase the emphasis on asset management in the transportation planning process.

- *Integrating Asset Management into the Transportation Planning Process* (FHWA-HIF-19-001).[41] This case study focuses primarily upon how the Northeast Ohio Areawide Coordinating Agency integrates TAM into the metropolitan planning process.

- *Enhancing Transportation: Connecting TSMO and Asset Management* (FHWA-HOP-18-094).[39] This fact sheet describes TSMO and the relationship between TMSO and asset management.

Other resources used in developing this report include:

- National Operations Center of Excellence (NOCoE) TMS Resources.[43] The NOCoE web page includes links to various resources, including reports, agency case studies, and webinars, developed to help agencies manage TMS assets. Resources relevant to this topic further link to separate NOCoE web pages that contain national resources and agency specific practices:
    - Assessing Traffic Management Systems (TMSs) Capabilities and Performance.[44]
    - Monitoring, Evaluating, and Reporting on TMS Performance.[45]
    - Inventorying and Assessing TMS Assets and Capabilities.[46]
    - Managing TMS Assets and Resources.[47]

- TMC Pooled-Fund Study Projects.[48] In addition to the project that generated this report, the TMC PFS has a variety of completed, current, and planned projects that will generate findings to help agencies manage TMS assets, including the TMC Performance Dashboards (FHWA-HOP-20-032).[49] This report examines the use of dashboards in the TMC environment and includes a process for planning and developing a successful dashboard.

- American Association of State Highway and Transportation Officials (AASHTO) TAM Portal.[50] This web page includes links to a variety of TAM-related resources, tools, and events. Of particular note are the following two resources, which are available on this website.
    - AASHTO TAM Guide.[51] This online resource addresses fundamental aspects of TAM practice for new and seasoned practitioners and executives to support understanding of agency asset management techniques and help advance asset management practices.

- AASHTO TAM Gap Analysis Tool.[52] This spreadsheet-based gap analysis tool and associated user guide was developed for State and local transportation practitioners to facilitate their implementation of TAM by helping to identify and prioritize needed enhancements.

- North/West Passage Pooled Fund Study Asset Management Practices for ITS Infrastructure.[53] A summary of ITS asset management practices generally and in States belonging to the Northwest Passage PFS.

- ENTERPRISE Pooled Fund Study The Evolution of ITS in Transportation Asset Management.[12] Summary of current ITS Asset Management efforts.

- NCHRP Report 800: Successful Practices in GIS-Based Asset Management.[54] Describes practices for inventorying transportation asset sin GIS and using that data to improve asset management.

- NCHRP Guide to the Integration of Transportation Systems Management and Operations into Transportation Asset Management.[55] Project website for an upcoming report providing insight on TAM as a key component of an agency's operations.

Other relevant resources that are available and may be of interest are presented in table 14.

Table 14. Additional resources for managing TMS assets.

Resource and Link	Description
Elements of a Comprehensive Signals Asset Management System (FHWA-HOP-05-006)(56)	FHWA report that describes the elements of a comprehensive signal system asset management system.
Asset Management Primer(57)	A high-level FHWA primer describing TAM and its value.
Asset Management and Safety Peer Exchange: Beyond Pavement and Bridges: Transportation Asset Management with a Focus on Safety (FHWA-HIF-12-005)(58)	Notes from an FHWA peer exchange workshop among States regarding asset management practices.
Generic Workplan for Developing a TAMP(59)	FHWA framework for States to use in developing a TAMP compliant with Federal requirements.
Life Cycle Planning – An Overview(60)	A short FHWA white paper that summarizes lifecycle planning and how it can improve the managing of assets.
Incorporating Risk Management into Transportation Asset Management Plans(61)	FHWA guidance on the risk element of the TAMP, with a definition of risk and how the risk element can be applied to meet risk-based TAMP requirements.
Asset Management: Risk Publications(62)	Series of FHWA reports describing various transportation asset risk types and how to incorporate those risks in TAM.
Asset Management: Financial Plans Publications(63)	Series of FHWA reports focused primarily on infrastructure assets, including guidance on valuing transportation assets.
Tools for Operations Benefit Cost Analysis (TOPS-BC)(64)	A sketch-planning level decision-support spreadsheet tool developed by the FHWA.
Using an LCP (Life Cycle Planning) Process to Support Transportation Asset Management: A Handbook on Putting the Federal Guidance into Practice (FHWA-HIF-19-006)(65)	Guidance from FHWA to support incorporating lifecycle planning into TAMPs.
Public Roads(66)	Quarterly magazine of FHWA includes articles relevant to managing assets. The linked article describes the creation of the FHWA Office of Asset Management.
MAP-21 – Moving Ahead for Progress in the 21st Century(67)	FHWA website with information about the 2012 legislation authorizing States to develop TAMPs.
Life-Cycle Cost Analysis Procedures Manual(68)	This manual provides LCCA procedures and step-by-step instructions on how to use *RealCost Version 2.5CA*, which is Caltrans' LCCA software based on FHWA *RealCost Version 2.5*.

Resource and Link	Description
Performance Measures and Health Index of ITS Assets[31]	Georgia DOT presentation regarding their definition of ITS assets, including TMS, and its process for measuring performance of those assets.
Minnesota DOT Major Equipment Lifecycle Cost Analysis[69]	Minnesota DOT report describing a method that permits equipment fleet managers to maximize the cost-effectiveness of the fleet by optimizing the overall lifecycle value of each piece in the fleet.
Intelligent Transportation Systems Maintenance Standards[70]	Pennsylvania DOT guidance for maintaining ITS assets, including those for TMS.
Pennsylvania DOT Central Regional Traffic Management Center Regional Operations Plan[71]	Operations plan for one region of Pennsylvania DOT, including inventory and operations costs for TMS assets.
Regional Operations Plan (ROP): Central RTMC Region[54]	Texas DOT publication that helps agencies define, develop, and implement asset management—particularly relating to establishing performance measures for safety and operations.
A Life-cycle Cost Analysis Approach for Emerging Intelligent Transportation Systems with Connected and Autonomous Vehicles[33]	White paper that describes five fundamental differences in LCCA for technology oriented ITS projects in comparison to projects such as pavement or bridge projects.
A Life-cycle Benefit/Cost Analysis Framework for ITS Deployments[73]	Dissertation from Syracuse University describing a comprehensive a framework to evaluate existing and anticipated intelligent ITS strategies, particularly, adaptive traffic control and ramp metering systems.
Optimizing Maintenance Equipment Life-Cycle for Local Agencies[74]	Iowa State University paper on guidance for local agencies to use data-driven methods for assessing equipment lifecycles.
"A Life-Cycle Benefit/Cost Analysis Framework for Adaptive Traffic Control Systems"[75]	Brief paper from the Institution of Civil Engineers presenting high-level benefit/cost analysis framework for adaptive traffic control systems.

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