APPLYING TRANSPORTATION ASSET MANAGEMENT TO TRAFFIC SIGNALS:

A PRIMER

January 2022

U.S. Department of Transportation
Federal Highway Administration

FOREWORD

Transportation Systems Management and Operations (TSMO) leverages technology to provide cost effective solutions to optimizing the performance of the existing transportation system. Such technology examples include traffic signals and Intelligent Transportation Systems (ITS) devices. As State and local agencies begin to develop their own best practices in maintaining their TSMO assets, practitioners should understand asset management principles in order to apply them in the most cost effective way. This primer provides information for applying Transportation Asset Management (TAM) principles to traffic signals in accordance with the Transportation Asset Management Plan (TAMP) requirements.

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16. Abstract

As the importance of an integrated transportation system continues to evolve and grow, U.S. transportation agencies are identifying traffic signals as critical elements in asset management and long-range planning. Current research continues to suggest that transportation agencies can benefit from including traffic signals in their asset management planning and integrating asset management practices for traffic signal assets. This primer provides information for applying Transportation Asset Management (TAM) principles to traffic signals in accordance with the Transportation Asset Management Plan (TAMP) requirements.

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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 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 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 (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the 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 ACRONYMS

ATSPM	Automated Traffic Signal Performance Measures
BIM	Building Information Modeling
BTG	Bridging the Gap
Caltrans	California Department of Transportation
CFR	Code of Federal Regulations
DOT	Department of Transportation
EDC	FHWA's Every Day Counts Initiative
EIR	Employer Information Requirements
FHWA	Federal Highway Administration
GIS	Geographic Information System
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
IT	Information Technology
ITS	Intelligent Transportation Systems
MAP-21	Moving Ahead for Progress in the 21st Century Act of 2012
NHS	National Highway System
RCM	Reliability-Centered Maintenance
SHS	State Highway System
SQL	Structured Query Language
TAM	Transportation Asset Management
TAMP	Transportation Asset Management Plan required under 23 U.S.C. 119(e)
TMS	Transportation Management Systems
TPM	Transportation Performance Management
TSMO	Transportation Systems Management and Operations
TSMP	Traffic Signal Management Plan

CHAPTER 1. INTRODUCTION

With increasing emphasis on setting and achieving targets for congestion mitigation and reliability, transportation agencies recognize the critical contribution of traffic signals to roadway performance. Asset managers of traffic signals have made significant strides in developing and maintaining comprehensive asset inventories driven, in part, by the prospect of better access to real-time information about how the transportation system is performing, allowing agencies to make more cost effective choices with limited maintenance dollars. Comprehensive inventories, when linked with performance data and replacement and maintenance costs, support greater accountability and better decisionmaking for managing resource investments. However, operational and performance data on these assets is often limited to device type, manufacturer/installer, location, and anticipated lifespan.

With a lack of detailed, reliable, and comprehensive real-time performance data, agencies continue to face challenges in planning for the entire lifecycle of traffic signals, which are not always included in the agencies' core planning and programming processes. However, as the Transportation Systems Management and Operations (TSMO) practice continues to evolve, U.S. transportation agencies are identifying signals as critical elements in asset management and long-range planning.

PURPOSE

This primer provides information for applying transportation asset management (TAM) principles to traffic signals assets. It also describes how transportation agencies can benefit from including traffic signals in their asset management planning and integrating asset management practices for traffic signal assets.

This primer provides information for transportation agencies responsible for:

- Managing and maintaining traffic signals.
- Improving asset management practices.
- Planning new traffic signal assets and understanding the long-term responsibility (and cost) involved.

The anticipated audience may include (but is not limited to) State departments of transportation (DOT), cities, counties, and other similar agencies. Although the primary objective of this primer is to equip State DOTs that wish to add traffic signals to their Transportation Asset Management Plan (TAMP) developed pursuant to 23 U.S.C. 119(e), this guide can also assist agencies looking to enhance their TAM practice for traffic signals apart from the TAMP, including local agencies.

PRIMER STRUCTURE

This primer has four key sections:

- ***Chapter 1: Introduction*—**Introduces the primer and its purpose.
- ***Chapter 2: Background*—**Provides the background, history, and importance of TAM, both in general and specific to traffic signals. This section also introduces the five emerging themes developed from the Federal Highway Administration (FHWA) research.
- ***Chapters 3 to 7: Emerging Themes for Applying TAM to Traffic Signals*—**Details five emerging themes in traffic signals asset management. For each theme, the chapter provides an overview, examples from various transportation agencies, and key actions that agencies can take when implementing asset management for traffic signals.
- ***Chapter 8: Summary*—**Summarizes the actions agencies can use to adopt and implement TAM for traffic signals.

CHAPTER 2. BACKGROUND

In recent years, asset management has grown in practice at transportation agencies throughout the world. In the United States, many transportation agencies have invested in implementing asset management principles.

TRANSPORTATION ASSET MANAGEMENT

TAM is used to manage the 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. ISTEA first established the use of management systems for roads, bridges, and other transportation assets.[1] More recently, MAP-21 required all State departments of transportation (DOTs) to develop risk-based TAMPs, a requirement that is continued in the Infrastructure Investment and Jobs Act.[2,3]

The FHWA has implemented the asset management requirements of 23 U.S.C. 119 by promulgating the asset management rule at 23 Code of Federal Regulations (CFR) part 515. The regulation defines asset management as:

> *A strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at minimum practicable cost.*[4]

Further, 23 CFR 515.7(a) requires State DOTs to develop a TAMP that describes how the agency will manage the National Highway System (NHS) to achieve system performance effectiveness and its targets for asset condition while managing risk, in a financially responsible manner, at a minimum practicable cost over the lifecycle of its assets.

FHWA developed guidelines and guidance to help transportation agencies design and populate a TAMP.[5] State DOT TAMPs must address eight key elements for NHS pavements and bridges.[6] Although encouraged, there are no requirements for addressing traffic signals in a TAMP. Some

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1 See ISTEA section 1009(e)(4) (codified as amended at 23 U.S.C. 119(e)).

2 See MAP-21 section 1106 (codified as amended at 23 U.S.C. 119(e)).

3 Public Law 117-58. This document was written before the enactment of the Bipartisan Infrastructure Law (BIL) in November 2021. The BIL amended 23 U.S.C. 119(e)(4) to add a requirement that the lifecycle cost and risk management analysis elements of a TAMP take into consideration extreme weather and resilience, but otherwise left the statutory requirements for TAMP elements unchanged from the requirements carried forward in the Fixing America's Surface Transportation (FAST) Act of 2015.

4 23 CFR 515.5.

5 FHWA's guidance on TAMP development is available at https://www.fhwa.dot.gov/asset/guidance.cfm.

6 23 CFR 515.9(d).

State DOTs did include traffic signals in their first iteration of their TAMP document. 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 also 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, including traffic signals. The following eight elements, extrapolated from 23 CFR part 515, can also be applied to traffic signals:

1. ***Summary Listing of Assets*** *(23 CFR 515.9(b)-(c) and (d)(3))*—A summary of assets, including a description of the asset condition.
2. ***Lifecycle Planning*** *(23 CFR 515.7(b))*—A process to estimate the cost of managing an asset class, or asset subgroup, over its whole life with consideration for minimizing cost while preserving or improving the asset's condition.
3. ***Asset Management Objectives*** *(23 CFR 515.9(d)(1))*—Objectives, aligned to the agency's mission, designed to achieve and sustain the desired state of good repair over the lifecycle of the agency's assets at a minimum practicable cost.
4. ***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 could include measurements and associated targets to assess the performance of the highway system as it relates to those assets.
5. ***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.
6. ***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.
7. ***Financial Planning*** *(23 CFR 515.7(d) and 515.9(d)(7))*—A long-term plan spanning 10 years or more, 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.
8. ***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.

TRANSPORTATION SYSTEMS MANAGEMENT AND OPERATIONS

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.*

The goal of TSMO is to maintain, and where possible, restore the performance of the existing system before it needs extra capacity.

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 also expands the range of mobility choices available to system users, including shared mobility and nonmotorized options.

Asset management works to enhance system performance with processes similar to TSMO but with a different focus. Asset management is concerned with preserving or improving the condition of assets, and TSMO focuses on preserving and maximizing safety, mobility, and reliability. However, both systems share a strategic, performance-based approach to monitoring performance and applying actions to reach targets.

TRANSPORTATION PERFORMANCE MANAGEMENT

FHWA defines Transportation Performance Management (TPM) as a strategic approach that uses system information to make investment and policy decisions to achieve performance goals. TPM provides key information to help decisionmakers understand the consequences of investment decisions across assets and improve communication of these decisions among all stakeholders.[7]

THE TSMO, TRANSPORTATION ASSET MANAGEMENT, AND TRANSPORTATION PERFORMANCE MANAGEMENT RELATIONSHIP

There is a close relationship between TPM and TAM in the Federal-aid Highway Program: both consider asset and system performance, risks, and available resources to achieve desired objectives over time. However, TPM focuses on the approach to managing transportation system performance outcomes, while asset management applies this approach to manage the condition of the infrastructure assets. Agencies should ensure their TPM approach is considered and integrated when implementing asset management as illustrated in figure 1.[8]

Traffic signal assets can play a critical role for an agency's achievement of the performance outcomes for which it is responsible. To effectively perform this role, an agency needs to understand the asset investment needs for traffic signal assets to deliver those performance outcomes.

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[7] FHWA "What is TPM?," https://www.fhwa.dot.gov/tpm/about/tpm.cfm.

[8] FHWA "How TPM and Asset Management Work Together," https://www.fhwa.dot.gov/tpm/resources/working.cfm.

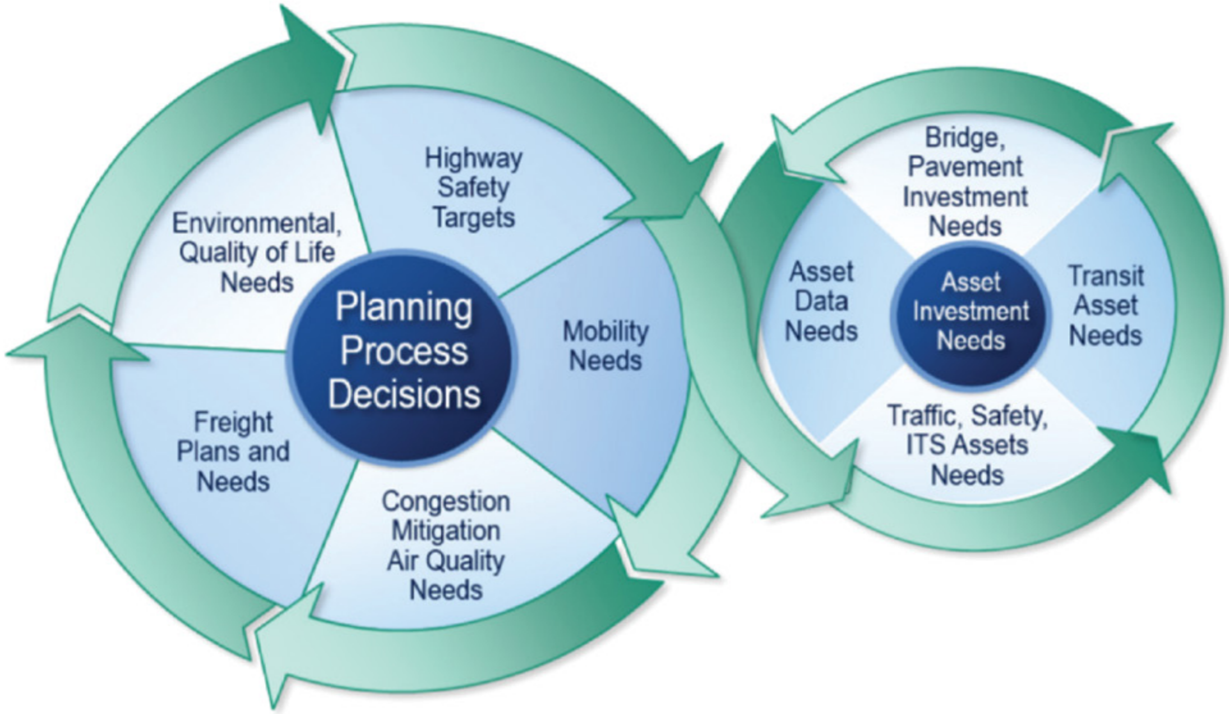

Figure 1. Diagram. Integration of Performance Management and Transportation Asset Management.
(Source: American Association of State Highway and Transportation Officials.)

EMERGING THEMES IN TRAFFIC SIGNALS ASSET MANAGEMENT

As the area of traffic signals asset management continues to develop, transportation agencies seek a more developed understanding of current practices and implementation efforts. This primer is structured around five emerging themes in traffic signals asset management and uses recent, relevant examples from agencies to provide suggested implementation steps. The five themes are summarized here and further expanded upon in subsequent chapters. These themes are extrapolated from TAMP elements to assist an agency in including traffic signals in its TAMP:

1. **Asset Identification.**

   TAMP Element: Summary Listing of Assets (23 CFR 515.9(b)-(c) and (d)(3)).

   Agencies should identify what asset information is needed, why it is needed, and how to use that information once it is collected. Collecting the right information at the right time can help agencies make informed decisions about long-term asset needs. This theme provides an overview of the type of asset information agencies should be collecting for traffic signals and why.

2. **Management Systems for Assets.**

   TAMP Elements: Summary Listing of Assets, Lifecycle Planning, Performance Gap Analysis, Risk Management, Financial Planning, Investment Strategies (23 CFR 515.7 and 515.17).

   A management system is a critical component of an overall successful asset management program, assisting the agency in managing and maintaining asset data across the entire lifecycle of its assets, from acquisition to disposal. Management systems are a collection of processes, procedures, tools, or software systems to help an agency collect and store information while providing analysis to inform asset management decisionmaking. A management system may be a software system, a procedure, or a simple tool (e.g., a spreadsheet) depending on the level of detail that is appropriate.

A management system may include, but is not limited to:

a. Collection and storage of asset inventory and condition information.

b. Work order and maintenance management.

c. Lifecycle modeling and planning, including, forecasting deterioration, and determining the benefit/cost over the lifecycle of assets to evaluate alternative actions.

d. Assessment of short- and long-term needs.

e. Recommended programs of work that maximize overall program benefits within the financial constraints.

An effective management system focuses on key information at the right level of detail. This theme addresses type of systems and how those systems should be implemented.

Note that State DOTs are required to meet minimum standards for developing and operating their bridge and pavement management systems as outlined in 23 CFR § 515.17. There is no requirement for pavement and bridge management systems or other management systems to be used for traffic signals, but similar procedures also could be used to enhance asset management decisionmaking for traffic signal assets.

3. **Performance Measures and Targets.**

TAMP Elements: Asset Management Objectives, Measures and Targets for Asset Condition, Risk Management (23 CFR 515.9(d)(1)-(2) and (6)).

A target is the level of progress or performance expected for an objective. Many agencies have noted that there is no consistent way to measure the condition of traffic signals (e.g., like the National Bridge Inventory scale for bridges). As a result, each agency determines how to best track and measure the performance of its traffic signals. Further, traffic signals have a variety of different components with different life expectancies and conditions, leading to uncertainty about how to best define their overall condition. This theme highlights some of the practices that agencies adopt to combat this challenge.

4. **Maximizing Performance—Lifecycle Planning.**

TAMP Elements: Lifecycle Planning, Risk Management Analysis (23 CFR 515.7(b)-(c)).

Lifecycle planning means a process to estimate the cost of managing an asset class, or asset sub-group over its whole life with consideration for minimizing cost while preserving or improving the condition. Many agencies are starting to adopt long-term maintenance plans and consider lifecycle analysis for traffic signals. It can be difficult to quantify funding needs, which can lead to inefficient and inconsistent approaches to maintenance. Further, agencies should plan for traffic signals to become obsolete or unsupported. In the highway industry, this unique challenge merits special attention. This theme looks at best practices for planning and maintaining traffic signals.

5. **Resource Allocation—Financial Plan, Investment Strategies, Performance Gap Analysis.**

   TAMP Elements: Performance Gap Analysis, Financial Planning, Investment Strategies (23 CFR 515.7(a), 515.7(d)-(e), 515.9(d)(4), (7)-(8), and 515.9(f)).

   A lack of a formal funding needs assessment for traffic signals as part of an asset management program may hamper long-term management efforts for these assets. There are opportunities to use asset management to improve in-reach (outreach within an agency) to build a stronger understanding of funding needs. Further, agencies are starting to use valuation-based approaches when it comes to needs assessments. This theme looks at recommended approaches for identifying and communicating those needs for traffic signals.

These five themes, aligned to the eight TAMP elements defined by FHWA (shown in table 1), can help agencies adopt leading practices for traffic signals asset management. Each theme is further explained in the subsequent chapters, including specific examples from State DOTs and recommended action steps for implementing asset management for traffic signals.

Table 1. Alignment of themes to transportation asset management plan elements.

Theme	TAMP Elements
1. Asset Identification.	• Summary Listing of Assets.
2. Management Systems for Assets.	• Summary Listing of Assets. • Lifecycle Planning. • Risk Management. • Performance Gap Analysis. • Financial Planning. • Investment Strategies.
3. Performance Measures and Targets.	• Asset Management Objectives. • Measures and Targets for Asset Condition. • Risk Management.
4. Maximizing Performance—Lifecycle Planning.	• Lifecycle Planning. • Risk Management.
5. Resource Allocation.	• Performance Gap Analysis. • Financial Planning. • Investment Strategies.

CHAPTER 3. ASSET IDENTIFICATION

A well-developed asset inventory (i.e., what do we have?) provides a basis for setting performance targets, allocating resources, and monitoring progress towards achieving objectives. Although an improved asset inventory for traffic signal assets is a desirable outcome to inform decisionmaking, collecting, maintaining, and managing an asset inventory can be expensive. Before undertaking inventory process enhancements and/or investing additional funds in data capture, agencies should understand what information is important for both current and future asset management decisions.

> **FHWA TAMP Element:** *Summary Listing of Assets* (23 CFR 515.9(b)-(c) and (d)(3))
>
> Asset identification aligns directly with one of the critical eight elements of a TAMP, a listing or an inventory of the agency's key assets. Although traffic signals are not currently required in a TAMP, many agencies desire to have an inventory of all assets within the right-of-way corridor. Traffic signals are increasingly being identified as critical assets to the successful operation and safety of the agency's infrastructure. Knowing and understanding the status and condition of these assets will allow the agency to make informed decisions about lifecycle planning and investment prioritization. Further, agencies should pay close attention to the type of data they are collecting and tracking against their assets. Tracking too little information will not provide the necessary value to make informed decisions, while tracking too much information results in unnecessary costs and unused data.

When making decisions about asset identification, it is important to consider the following ideas:

- **Asset Definition—**What to define/consider as assets?
- **Asset Attributes and Hierarchy—**What information should be collected for these assets?
- **Asset Inventory Management—**How will the agency collect and manage asset information so that it remains accurate and reliable?

With all these ideas, it is important to consider how the data supports the agency's decisionmaking relative to its overarching asset management goals, objectives, and performance targets.

ASSET DEFINITION

As defined in 23 CFR 515.5, "asset" means:

> *[A]ll physical highway infrastructure located within the right-of-way corridor of a highway. The term asset includes all components necessary for the operation of a highway including pavements, highway bridges, tunnels, signs, ancillary structures, and other physical components of a highway.*

This definition focuses on physical assets and all components necessary for the operation of a highway. However, with regard to traffic signals, asset-management-related factors beyond the physical features and functionality of the traffic signal should be considered. For example, if all the components of a set of traffic signals at an intersection are in good physical condition, they may not function as designed because of old controller software, poor physical condition of a supporting asset, or outdated signal timing plans. These items are critical for maintaining safety and mobility and their condition should be monitored carefully. Agencies should carefully consider including these factors when adopting traffic signals asset management.

Most agencies categorize traffic signals separately from Intelligent Transportation Systems (ITS) assets for several factors such as asset ownership, varying maintenance and operational responsibilities, liability concerns specific to traffic signals, and for the capabilities of recording and managing asset information. While not as common, some agencies include traffic signals and ITS assets in one asset class, especially smaller agencies with fewer assets. Currently, agencies collect a variety of information, from geographic coordinates, conditions, serial numbers, and age to energy consumption, condition of structural support, and driving/work time associated with asset work orders.

ASSET ATTRIBUTES AND HIERARCHY

Agencies should identify a clear set of baseline data necessary for traffic signals asset management planning. Numerous agencies are just beginning to build out databases and lack a precise understanding of what information will aid future decisions. Agencies should follow an iterative approach when it comes to identifying the type of data to collect for traffic signals.

National Cooperative Highway Research Program (NCHRP) 08-36, Task 114: Transportation Asset Management for Ancillary Assets identifies ancillary asset inventory needs at an enterprise level and asset-specific level (Rose et al. 2014). At an enterprise level, knowledge of the complete asset inventory is recommended along with an understanding of interactions with other asset classes and the relationship of the asset class to overall safety, mobility, and asset performance. At the asset level, inspection and condition assessments, performance metrics, lifecycle management plans and practices, asset priorities, and decision support are all valuable. Further, an asset class and/or an asset subgroup level view of assets can provide powerful insights for addressing, maintaining, and managing a collection of assets. Figure 2 illustrates this framework.

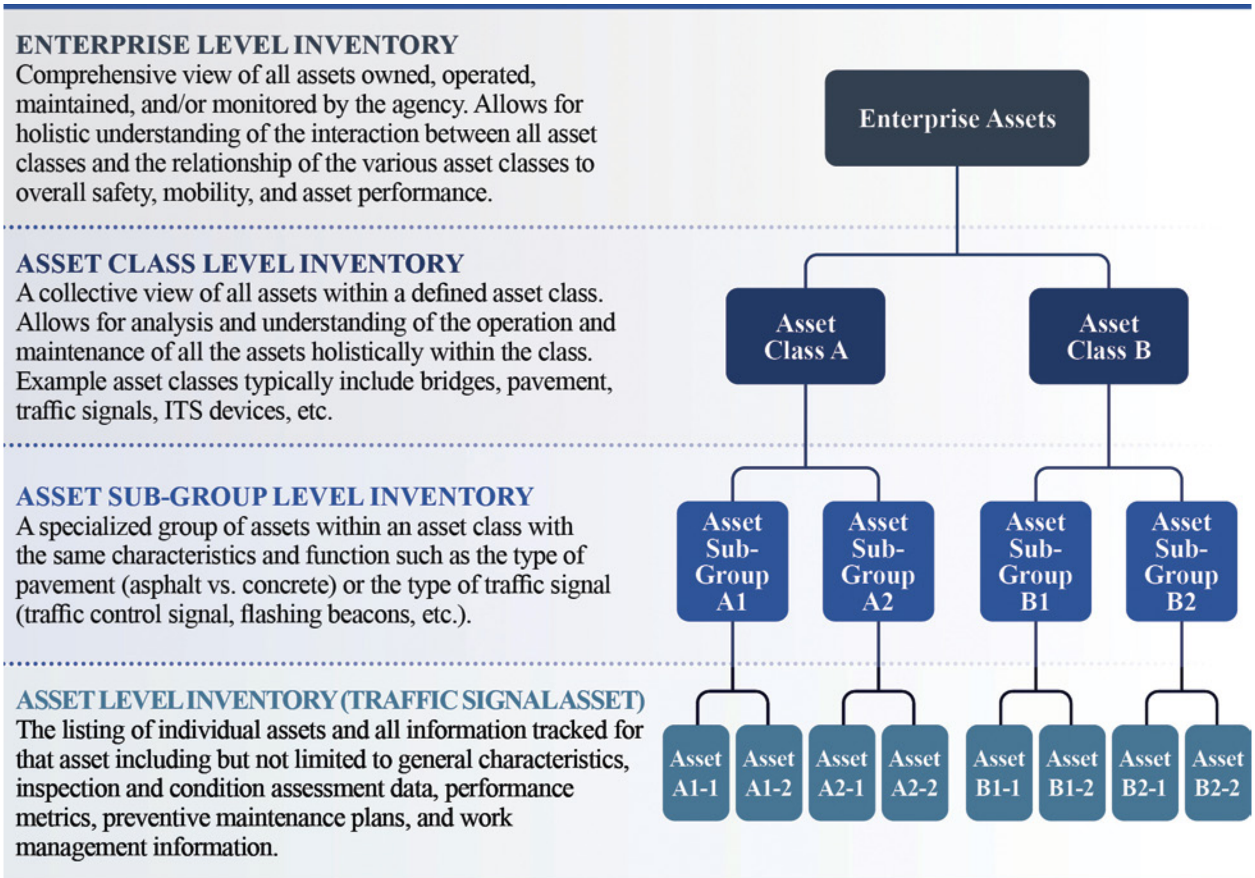

Figure 2. Diagram. Asset inventory definitions framework.
(Source: FHWA.)

The first decision is the level of detail to be used. Relevant definitions from 23 CFR 515.5, are:

> *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 (IT), signs or lighting)....*
>
> *Asset sub-group means a specialized group of assets within an asset class with the same characteristics and function (e.g., concrete pavements or asphalt pavements).*

State and local agencies using these definitions have flexibility to categorize their traffic signals. Although agencies may group their assets along traditional functions (e.g., traffic signals, ITS devices), they can also group assets with other assets that serve a broader function (e.g., intersections). Many agencies start by tracking the traffic signal as a whole, while other agencies have begun tracking the individual asset components that make up the traffic signals. See figure 3.

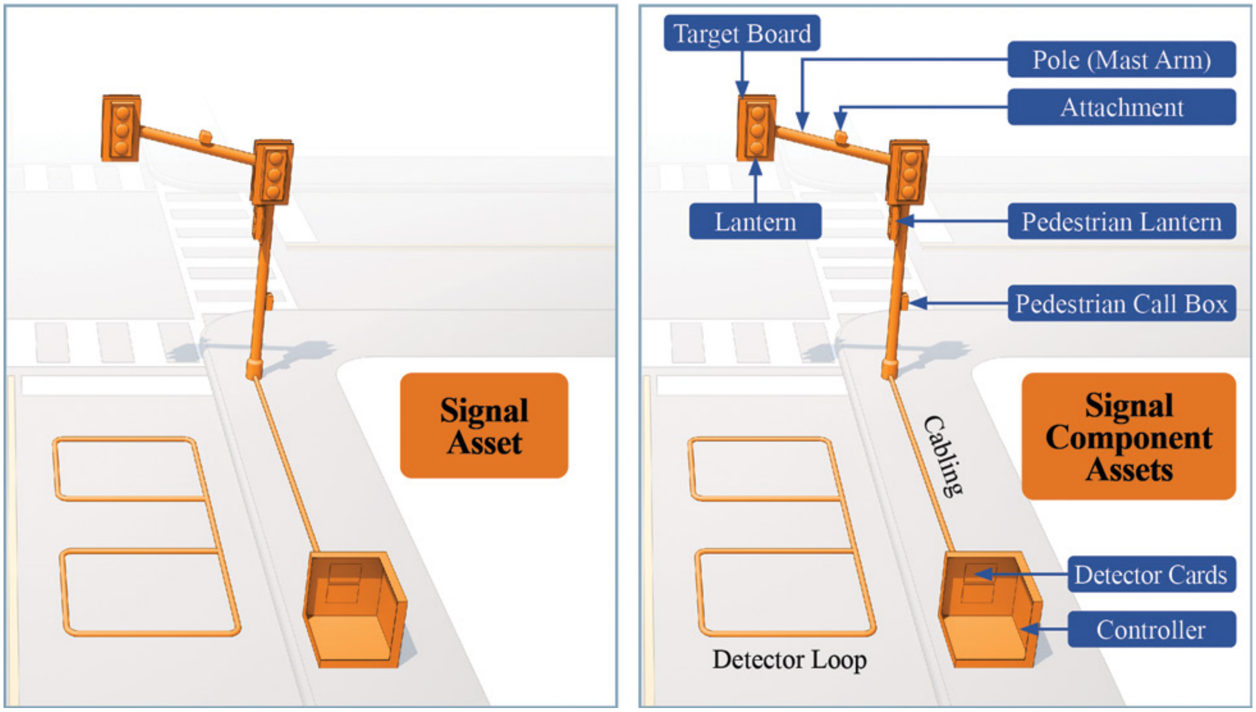

Figure 3. Rendering. Traffic signal assets level of detail.
(Source: FHWA.)

Level of detail is linked to decisionmaking needs. Long-term needs can be calculated based on the expected life of a set of signals. However, components of a traffic signal have differing useful lives (e.g., the mast pole might have a useful life of 40 years, but the signal itself may become obsolete or fail after 20 years). If agencies require component-level information, they can also stage the development of this detail. The focus may start on assets that require periodic maintenance and replacement, which can be planned. If the component replacement is reactive and not planned, requiring a decision about when to intervene, then further asset information is likely to be less critical.

Asset Hierarchy Framework—Oregon Department of Transportation

Oregon DOT's inventory highlights the importance of location in its asset inventory for both traffic signals and ITS assets—capturing the location, asset class, and asset subgroups. At the highest level of its asset hierarchy, Oregon DOT has traffic signals and ITS cabinets, and then breaks those assets down to lower level assets and components.

Oregon DOT reviews its data regularly and is cognizant of what it is tracking and how the data are being used. The agency is reviewing what lower level traffic signal components should and should not be tracked, as the agency does not want its technicians to get bogged down tracking information that is not necessary. Further, Oregon DOT does track serial numbers for critical components, primarily for warranty management.

Table 2 complements figure 3, outlining some of the common components and attributes agencies can track for traffic signals. Although it is not a comprehensive list, it provides an initial snapshot of what agencies are starting to track for traffic signals. Note that several of the items listed in table 2 (such as signal head and controller), although considered "components" to the traffic signal, can still be tracked as individual assets. This table only shows the potential breakdown of an agency's traffic signal assets.

Table 2. Common traffic signal components, items, and attributes.

Name	Attribute
Traffic Signal	• Signal Type. • Manufacturer. • Model/Serial Number. • Installation Location.
Signal Head	• Head Type/Material. • Configuration. • Lens Type. • Bulb Type.
Controller	• Type. • Make. • Model.
Communication Devices	• Remote Communication. • Device Type (e.g., GPS clock, radio). • System Type (isolated, closed loop, central).
Pole/Structure/ Foundation	• Pole/Structure Type. • Pole/Structure Style. • Pole/Structure Base Type. • Pole/Structure Length/Height.
Detection System	• Detection Loop Size. • Detection Loop Type. • Camera Type. • Radar Type.
Controller Software[1]	• Name. • Version. • Firmware.
Signal Timing Plan[1]	• Last Updated. • Key Parameters.
Power	• Power Type. • Uninterruptable Power Supply. • Batteries.

[1] These can be thought of as specific items or be linked as attributes to one of the asset components (e.g., controller software as an attribute for the controller).

The items referring to controlling software and signal timing plans in this table highlight the importance of considering the functionality of traffic signals in addition to the physical condition as part of the agency's asset management initiatives. While the physical condition of a signal is critical, the impact to system performance should also be considered. Operating signal assets may involve activities beyond their physical features and cover functionality, such as maintaining controller software and signal timing plans. Consideration of an asset's functionality as part of an asset management strategy is consistent with the framework for asset management as the term is defined in 23 U.S.C. 101(a)(2).

ASSET INVENTORY MANAGEMENT

Asset inventories should include a procedure for collecting, processing, and updating inventory and condition data. Having a comprehensive, up-to-date asset inventory supports decisionmaking, performance target tracking, lifecycle modeling, projecting funding needs, and allocating funds; however, maintaining a comprehensive inventory of traffic signals can be a challenge. Because traffic signal assets often have short design lives, agencies frequently plan to operate them until they become obsolete or are no longer functioning as originally intended rather than carefully managed over their entire lifecycle, although this trend is beginning to change as many agencies have identified the importance of this asset.

Asset Attribute Collection—Utah DOT

The Utah DOT TAMP outlines a data-driven, performance-based approach to allocating transportation funds to manage its pavements, bridges, advanced traffic management systems (or as referred to in this guide, ITS), and signal devices. The Utah DOT Asset Advisory Committee/Performance Management Group developed a tiered system to prioritize the most valuable assets and those with the highest risk to system operation. To achieve its safety and mobility strategic goals, Utah DOT included traffic signals and ITS devices in the highest tier for management (alongside pavements and bridges). Its highest tier is "performance-based management," which requires accurate data collection, performance target setting and tracking, predictive modeling and risk analysis, and dedicated funding.

When traffic signals and ITS assets were added as a Tier 1 asset in 2016, Utah DOT needed to ensure that the right data were collected at the right time. Utah DOT understood the importance of having a good management system and, more notably, the importance of having buy-in across the agency and a solid implementation plan for data collection. Utah DOT identified four critical factors for implementing a data collection framework:

1. Limit the number of assets and attributes being tracked (i.e., focus on the actual assets and data to collect—not collecting data for the sake of collecting data).
2. Use a robust work order management system (either as part of a comprehensive management system or a system that interfaces directly).
3. Ensure staff understand the purpose behind the data collection.
4. Make the hardware for data collection mobile.

These four steps are applicable throughout the Utah DOT data collecting lifecycle of the asset (inventory data, work management data, condition data). Utah DOT noted the importance of taking baby steps. For traffic signals, to ease into implementation, the agency first identified four key attributes it wanted to collect: signal type, key components of that signal, manufacturer, and model. Utah DOT worked with its technicians to convey the need for the information and provide training. The technicians then went to the field and started tracking this information and populating work orders. After about three months, Utah DOT met with the technicians to see how the process was going and identify any problems. Utah DOT then incorporated this feedback, updated the system and/or process as needed, and provided additional training. Utah DOT has continued to expand upon this approach for traffic signals and ITS assets since 2016. The feedback from the technicians helps the agency pinpoint what data and information it wants to collect on its assets.

(Source: Utah Department of Transportation 2019.)

KEY ACTIONS

Agencies can adopt or improve upon several key actions when implementing asset identification for traffic signals.

Define and Collect Asset Attributes for Traffic Signals

Agencies should clearly define what information they are tracking against their assets and why they are tracking that information. Many factors may affect attribute collection, including institutional practice, location, safety, and operational criticality.

Key Steps:

- Similar to what is being tracked for other assets within the agency, an agency should begin collecting basic attributes like name, manufacturer, and install date as well as attributes that are specific to traffic signals. Having a clear list of these attributes will make it easier to explain to employees why certain information is being collected and to aid employees in asset collection and adoption. Further, this list can easily be shared with contractors when onboarding new assets.
- Add attribute data collection incrementally by introducing new types of attributes over time and/or through a phased approach. Agencies should closely monitor how the data are being collected, when they are being collected, and then obtain feedback from employees while both collecting and using the data. The agency then can adjust its processes around these attributes and begin to introduce additional attributes, as applicable.

Define and Collect Asset Attributes for Traffic Signal Components

Agencies should also define the level of detail they are collecting. This can be done by developing an asset hierarchy, a framework illustrating the relationship between assets and components.

Key Steps:

- Identify the most critical components of the traffic signal. What components are failing the most or what components are regularly being worked on? Start by identifying these components, and this will become the second layer of the hierarchy for the traffic signal. Table 2 provides a list of common components.
- Begin collecting a modified list of attributes for these second-level components. As the data are being collected, identify additional components or subcomponents. This will serve as the foundation for the agency's traffic signal hierarchy.

CHAPTER 4. MANAGEMENT SYSTEMS FOR ASSETS

A management system is a critical component of an overall successful asset management program, assisting the agency in managing and maintaining asset data across the entire lifecycle of its assets, from acquisition to disposal. A management system may be a software system, a procedure, or a simple tool (e.g., spreadsheet) depending on the level of detail that is appropriate.

FHWA TAMP Elements: Summary Listing of Assets, Lifecycle Planning, Performance Gap Analysis, Risk Management, Financial Planning, Investment Strategies
(23 CFR 515.7(a)-(e), 515.9(b)-(c), and 515.9(f))

A management system supports multiple components of an agency's asset management program. The foundation of a system starts with good asset data and an accurate asset inventory. This theme is extrapolated from various TAMP elements, but most critically the asset identification element. When adopting or building out the agency's traffic signal asset management program, ensuring the right asset data are defined, collected, and tracked is essential for further development and adoption of the additional elements discussed in this primer.

When considering a management system, an agency should consider:

- System Functionality—What information management and decisionmaking assistance is desired?
- Location-Specific Functionality—How is asset location information stored?
- System Interfaces and Integrations—What relationships to other agency systems are needed for sharing information?
- System Implementation and Adoption—What needs should be considered to achieve a successful and long-lasting implementation?

SYSTEM FUNCTIONALITY

System functionality covers the critical aspects of the asset management spectrum such as inventory, condition, work management, and materials management. Table 3 describes common functionalities as the basis for good asset management decisionmaking. Although 23 CFR 515.17 describes minimum standards for developing and operating bridge and pavement management systems, no requirements exist for management systems for traffic signal assets. This chapter focuses on the characteristics and benefits of a management system to support decisionmaking. Many of the principles are aligned with the minimum requirements in 23 CFR 515.17 for pavement and bridge management systems, but section 515.17 does not define requirements for traffic signals.

Table 3. Potential functionality of management systems for traffic signal assets.

Functionality	Brief Description
Asset Identification	Supports foundational data structure and data management, including processing, storing, and updating inventory data owned, managed, and maintained by the agency.
Asset Condition	Process, store, and update condition data. Usually based on basic condition scoring criteria for each asset class and type using a condition rating scale (e.g., standard 1 to 5 scoring).
Workplanning and Management	Supports the planning, scheduling, management, and tracking of various maintenance management activities performed on the assets and tracking and costing of work performed. Recommending programs and implementation schedules to manage the asset condition within policy and budget constraints.
Materials Management	Track and manage parts used to support asset management, including warehouse storage and items used during work management.
Warranty Management	Identify asset warranties, including the warranty terms and the party responsible for warranty service.
Planning and Budgeting	Capability to calculate and analyze costs associated with the operation and maintenance of assets, supporting long-term lifecycle planning and capital programming efforts. Likely to include forecasting deterioration of assets, assessing the benefit/cost over the lifecycle of assets to evaluate alternative actions (including no action decisions) for managing the condition, identifying short- and long-term budget needs for managing the condition.
Modeling Analytics	Identify priorities and targets for the various asset classes, types, and maintenance features—minimizing maintenance cost and optimizing asset utilization. Determining the strategies for identifying projects that maximize overall program benefits within the financial constraints.
Management Reporting	Generate and distribute reports and display dashboards and metrics for conveying asset management outcomes.

LOCATION-SPECIFIC FUNCTIONALITY

Agencies may use geographic information systems (GIS) and cloud-based, automated systems to identify and track assets. For example, some agencies have an integrated asset inventory with GIS that captures geographic information and assigns attributes (such as cabinet types or attached devices) to help inform future decisions for assets. Other agencies focus on providing a cloud-based, self-service tool for local agencies to manage traffic signals and share data through a centralized, GIS-compatible platform.

SYSTEM INTERFACES AND INTEGRATIONS

Management systems are more effective when they interface with other key enterprise systems, including an enterprise resource planning system (specifically for financial and human resource needs), document management, procurement/third-party contract monitoring, and various operation-based and monitoring systems. Most agencies have multiple information technology (IT) systems to manage, maintain, and operate their assets; each agency should ensure that its systems are properly integrated and sharing appropriate data. Many agencies noted that this can be difficult because systems often are added in isolation and are not properly linked. As a result, data in one system does not match the data in another, users must log into multiple systems to get the information, and the agency does not have a single source of record for its assets.

Several agencies identified a challenge with asset management and maintenance management software programs not being able to "talk" to each other, which may result in duplicate data, the inability to pull comprehensive data queries, and uncoordinated maintenance treatment plans. Agencies also should introduce tools that are easy to use in the field; tools and processes should be well-understood by the technicians, who need to know what the tools measure and why that data is being collected. Other agencies noted that the key to tracking information is to keep it simple, otherwise, employees will likely not input the information. Further, documenting copious amounts of information can overburden crews and may result in sporadic updates to the asset record.

SYSTEM IMPLEMENTATION AND ADOPTION

When implementing a new software system or an approach to collecting asset data, normally it is best to introduce the tool and process iteratively across the agency. Some agencies have been using a dedicated asset management software system to manage only their traffic signals. These tools typically have traffic signal specific features, such as inventorying the assets by location/intersection and tracking traffic signal performance measures. With that said, it can be cumbersome to use these asset-specific systems in conjunction with other agency-wide tools. As such, many agencies are looking to improve and advance their management systems, including consolidating their tools and/or broadening the features/functionality so the systems can be used for other asset classes.

Connecticut DOT started using its traffic signal energy consumption tracking tool (a Structured Query Language (SQL) database) to track asset-related data for traffic signals as well. This adoption was a natural progression for the agency: it saw a gap in data, the field was added to its database, and data started being collected. This approach and typically results in the least amount of push-back, because stakeholders are slowly introduced to the new process.

Implementing Management Systems—Connecticut DOT

To advance asset management practice in the organization, Connecticut DOT's TAMP includes five additional assets beyond the Federal statutory requirements: traffic signals, signs, sign supports, pavement markings, and highway buildings. Connecticut DOT's TAMP establishes a process for tracking and recording its assets' inventory and condition.

To include within the TAMP an inventory of traffic signals, Connecticut DOT used a traffic signal database initially designed for operational purposes to track power consumption as the basis for billing for power. Data are stored in an SQL database with a Microsoft Access front end for data entry and viewing. The database has been expanded over time to store locations, signal type, ownership, maintenance responsibility, estimated energy use, pedestrian features, lamp type, and other attributes. Connecticut DOT notes that they are exploring conversion to a more robust database and collecting additional traffic signal details, now that the agency relies on the database for more asset management planning purposes.

Connecticut DOT has been specifically intentional when identifying which attributes it collects and tracks for its traffic signals. The agency's Traffic Safety Group recently conducted a study on the safety of critical traffic signals. Although the study's purpose was to assess the safety impacts of these traffic signals, it was determined there would be a benefit to collecting additional traffic signal data under the study beyond what was currently being tracked in the inventory, including type of span configuration, number of artery signal heads, presence of artery detection, left-turn phasing on artery, and left-turn phasing on side street. The agency saw an opportunity to repurpose the data for future asset management related needs. As a follow-on to this effort, Connecticut DOT is identifying additional, more pertinent attributes to track for enhanced management of traffic signals.

(Source: Connecticut Department of Transportation 2019.)

Adopting New Management Systems—Minnesota DOT

Minnesota DOT recently implemented a new asset management software system, for both traffic signals and ITS assets, and reported positive feedback and adoption since the release. Although the new system has only been in place since 2018, Minnesota DOT already noted it is extracting good data and findings from the system, to help with lifecycle cost and maintenance planning.

This effort was several years in the making. Like many agencies, Minnesota DOT was challenged at collecting and tracking its asset data consistently and comprehensively across all asset departments. With the increasing importance of asset management for additional assets outside of bridges and pavements, Minnesota DOT knew it would be important to purchase and implement a more robust management system. Signals and ITS assets were the first assets onboarded to the new system.

Reasons for the implementation's success included:

- ***Implementation Team Support***—Minnesota DOT allowed the system implementer to be heavily involved throughout the entire process, allowing for this through procurement. Finding the right implementer was key.
- ***Dedicated Internal Resources***—Recognizing the need to have internal employees lead and oversee system implementation, Minnesota DOT included this as part of its system implementation budget.
- ***Stakeholder Involvement***—Minnesota DOT made sure to involve all stakeholders and future users, across departments, in system decisionmaking.
- ***System Interfaces***—The IT department was heavily involved, to ensure proper onboarding, implementation, and interfaces were set up across already existing systems from the outset. Minnesota DOT noted the importance of involving its technicians, the individuals using the system daily. This also included identifying system champions, who took pride in the new system, understood its benefit, and wanted to see widespread adoption across the agency.
- ***Reporting for Monitoring***—Because of the seamless interface and process link between accounting (timesheets) and the maintenance management system, the asset management team was able to get weekly reports on whether work on asset maintenance was being linked to the specific asset. Team members were then able to follow up with individuals (using dedicated internal resources) to work out why this was not happening and improve behaviors.

(Source: Minnesota Department of Transportation 2019.)

KEY ACTIONS

Agencies can adopt or improve upon the following key actions when implementing a management system for traffic signals: identifying system requirements and developing a stakeholder engagement plan.

Identify Management System Requirements, Gaps, and Interfaces

Before adopting a management system for traffic signals, the agency should review the current landscape of its asset and asset-related systems. This ultimately will help identify any systems that could be repurposed for traffic signals and identify systems that may be out-of-date. Further, this will help identify how assets and asset-related technology and information will drive more efficient and effective decisions and management actions through the asset's lifecycle—establishing both the landscape of information that needs to be made available and the functional requirements for technology to support full use of the information.

Key Steps:

- Seek feedback from employees who will be expected to use the system. Include how employees are using any current systems, what problems they are experiencing with those systems, and what functionality they would like to see in a new/upgraded system.
- Identify all existing systems and interfaces that are used to manage, maintain, monitor, and/or operate the agency's assets. Document current and/or potential interfaces, both automated and manual.
- Develop a list of requirements based on the feedback from step 1 and interface needs from step 2. This will allow the agency to better understand the state of its TAM systems and will allow the agency to be more proactive when looking to: (a) identify a new system; (b) upgrade its current system; or (c) build or continue to enhance a system internally.

Develop a Stakeholder Engagement Plan for System Implementation

Although an external system implementer can ultimately help lead the agency's implementation of a new or updated management system, the agency should carefully consider related cultural and institutional changes. Developing a plan that outlines how various system stakeholders will be involved throughout the implementation plan (or a Stakeholder Engagement Plan), can improve overall adoption.

Key Steps:

- Put in place an internal steering and/or technical committee to oversee system implementation. This committee should review progress, system onboarding, and integration within the agency's overall network. The committee should be made up of a variety of individuals holding different roles across the agency (e.g., maintenance technicians, operational employees, supervisors, senior management, and information technology).
- Identify and ensure the implementation of a pilot that focuses on a specific asset class/type or a specific region. Start small and do not try to address all assets right away. The agency should also only focus on a limited number of asset data attributes.
- Meet regularly to collect feedback (e.g., two to six times a year) with both frequent and infrequent users. This will not only help improve the pilot but also future growth of the system (e.g., additional asset classes and additional attributes).

CHAPTER 5. PERFORMANCE MEASURES AND TARGETS

Identifying objectives is a key element of effective asset management. TAM objectives should align with the vision and mission of the agency. To achieve these objectives, performance measures should then be identified and tracked.

> **FHWA TAMP Elements: Asset Management Objectives, Measures and Targets, Risk Management** (23 CFR 515.9(d)(1)-(2), (d)(6))
>
> This theme is extrapolated from three TAMP elements: asset management objectives, performance measures and targets, and risk management analysis. Once an agency has developed its asset management objectives, it can move forward in setting performance measures and targets to achieve those objectives. This emerging theme addresses common performance measures for traffic signals asset management that should then ultimately be linked to the agency's objectives around these assets. Performance measures can provide excellent insights on assets condition and operational status, helping the agency make better data-driven decisions and better assess, manage and mitigate related risks.

Establishing performance targets allows agencies to track progress towards their goals and guide the allocation of resources to projects and programs with significant impacts on performance. Performance targets should be based on projected available transportation funds and aligned with applicable Federal requirements and State goals and objectives. For traffic signals, and most asset classes in general, agencies have found it critically important to track multiple performance measures, aside from age and/or just condition.

Many international transportation agencies and an increasing number of U.S. agencies have noted the importance of tracking **asset availability**, or the "calculated percentage of time the asset is in a nonfailed state over a period of time. The asset is categorized to be in a failed state if it is in a degraded state or unavailable, or both" (Luk et al. 2013). This definition was created by Austroads, an association of transportation agencies in Australia and New Zealand that creates guidelines, codes of practice and research reports to promote best practices for road management. Austroads describes asset availability as the result of the combined effect of asset reliability/condition and asset maintainability/serviceability, more specifically:

- ***Asset Reliability/Condition***—Continuous performance of an asset to its design/intended function without failure under normal conditions during a period of time. It can be calculated as failure frequency or mean time between failure as well as defined by the age and visual condition.
- ***Asset Maintainability/Serviceability***—The time it takes to restore the asset when it fails. It can be calculated as the mean down time (i.e., covering fault identification, response and repair time) or assessed by the type and frequency of maintenance performed on the asset (e.g., preventive versus reactive maintenance, maintenance response time).

Austroads explains that asset availability can be enhanced by either improving reliability (i.e., reducing faults) and/or improving maintainability (i.e., quickly identifying and rectifying faults). These two performance measures are further explained and illustrated below.

With the expansion of centralized systems with communication to each signal, it is more feasible to monitor signals for downtime due to power outages, light failures, and other electronically trackable issues than it was years ago, when most signals were operated in isolation with no communications or tracking ability. Agencies now can assess the risk of signal failure/downtime and target fixes (i.e., if a signal has an inordinate number of power outages, it may be justifiable to install a battery backup system to keep the signal operational).

Also, as more agencies quantify their actions (asset deployment or maintenance for example) through a benefit/cost approach, risk for signal failures can be measured more effectively (more traffic moving fast equals higher risk if signal fails) to prioritize proactive maintenance/risk mitigation.

ASSET RELIABILITY/CONDITION

Asset condition is the foundational measure for the health and physical integrity of an asset and the reliability of the asset. In many cases, agencies measure condition based on age or remaining useful life. This is a valid approach, especially when just getting started in asset management for the respective asset class, in this case traffic signals. Agencies are starting to adopt more robust approaches for traffic signals condition, however, including visual condition scores based on visual inspection, age, and component assessments, rather than purely age or overall asset assessment.

Setting Performance Measures—Utah DOT

As part of a strategic goal of preserving infrastructure, Utah DOT sets performance measures and targets for signal systems, such as the percent of signals that are in good or fair condition, based on an annual inspection of all electronics and the physical infrastructure associated with signal systems. Utah DOT collects and posts its data and performance measures publicly, which contributes to its long-term planning success. Further, the agency has benefited from experienced senior leaders overseeing and championing the planning process. The agency lists key measures and targets for traffic signals in its dashboard and provides a visual representation to help convey outcomes to the public. Table 4 illustrates some of Utah DOT's traffic signal performance measures.

Table 4. Traffic signals and intelligent transportation system performance measures for Utah Department of Transportation.

Measure	Target
Number of traffic signals	–
Maintenance funding/traffic signal	$3,400/year
Connected signals that are communicating	97.5%
Average time to close signal maintenance work order	5 days or less
Signals with preventative maintenance performed	100%
Traffic signals/signal technician	50 maximum
Traffic signals/signal engineer	100 maximum
Construction projects reporting lane closures	90% key routes reporting
Lane closures activated changed or canceled	85% by June 2018
Planned events managed	90% Level 1 events by June 2018
Road weather information system devices operational	95%

Another framework for agencies is the use of Automated Traffic Signal Performance Measures (ATSPM), which were developed as part of the FHWA's Every Day Counts (EDC) initiative. EDC is a State-based model that identifies and rapidly deploys proven, yet underutilized innovations to shorten the project delivery process, enhance roadway safety, reduce traffic congestion, and integrate automation. (FHWA 2020)

ATSPM, which were released as part of EDC Round 4 (EDC-4), are a suite of performance measures, data collection tools, and data analysis tools to support the objectives and performance-based approaches to traffic signal operation and management. The use of ATSPM ultimately helps the agency improve the safety, mobility, and efficiency of signalized intersections for all users.

ATSPM consist of a high-resolution data-logging capability added to existing traffic signal infrastructure and data analysis techniques. This provides agency professionals with the information needed to proactively identify and correct deficiencies. They can then manage traffic signal maintenance and operations in support of an agency's safety, livability, and mobility goals. Agencies have been moving to this system to improve safety and customer service, and deal with scarce funding and staffing by providing continuous performance monitoring capability.

Further, several agencies have noted that ATSPM have been helpful in monitoring traffic signals and addressing issues from a centralized location. One of the primary uses for this approach is to make well-informed timing adjustments. Employees at an agency's central office get alerts and can focus on updating the signal remotely. ATSPM provide agencies with continuous performance monitoring capabilities based directly on actual performance, without dependence on software modeling or expensive, manually collected data.

These performance measures help link TPM and TAM. They improve the understanding of both performance and needs to assist in overall decisionmaking.

Condition Ratings—Connecticut DOT

Currently, Connecticut DOT estimates traffic signal condition based on lifespan, where traffic signals 26 years and older are expected to be in poor condition, and those below 15 years old are assumed to be in good condition. The agency uses the percentage of traffic signals in a state of good repair (good or fair condition, <25 years old) as its traffic signal performance measure. The current traffic signal performance is 74.5 percent (figure 4).

While Connecticut DOT started its traffic signals condition assessment with an age-based approach, the agency plans to move towards a component-based approach, incorporating both age and condition of the traffic signal components.

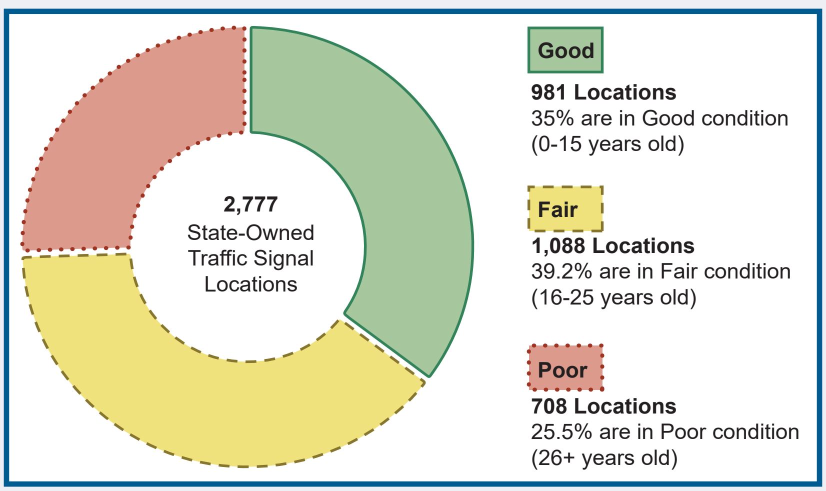

Figure 4. Graph. Connecticut Department of Transportation condition ratings.
(Source: Connecticut Department of Transportation 2019.)

ASSET MAINTAINABILITY/SERVICEABILITY

Asset maintainability (sometimes referred to as asset serviceability) is the measurement of the type and frequency of maintenance performed on the asset. Although this may not translate directly to the asset's reliability or condition, it can provide a good indication of the potential for assets to deteriorate more quickly than planned.

Common maintenance performance metrics may include but are not limited to percent of preventive maintenance versus reactive maintenance, time between initial service request and resolution, and maintenance funding per signal.

Asset Performance Measures—Seattle DOT

Seattle DOT started implementing asset management in 2007. Seattle DOT adopted a process of continuous improvement and expanded its asset management planning over time. ITS was added as a new asset class to its 2015 Status and Condition Report. Seattle DOT includes beacons, Bluetooth/Wi-Fi readers, camera assemblies, the communication network, counters, dynamic message signs, network hubs, radar speed signs, the transportation operations center, and traffic signal assemblies under this category.

Seattle DOT provides descriptions of good, fair, and poor rating standards for all devices, and it includes physical condition and operational condition categories. Performance measures for traffic signals are included as part of Seattle DOT's Bridging the Gap (BTG) program. BTG was conceived as a nine-year levy program (mainly from a parking tax) in response to 35 years of deferred maintenance due to shrinking transportation revenues. Seattle DOT gained BTG revenue of more than $40 million per year from 2007 through 2015 (the year the report was published). This revenue also allowed it to further leverage grant funding for infrastructure replacements.

Table 5 shows some of the traffic signal and ITS performance measures used for the BTG program. Additional measures are included in the 2015 Status and Conditions report for each device type.

Table 5. Seattle Department of Transportation asset measures and results.

Policy Goal/Performance Measure	2014 Planned	2014 Results	2015 Planned	Goal Met
% of Transportation Operations Center downtime due to planned maintenance	0.01%	N/A	0.01%	•
Traffic Signal Assemblies—% of downtime due to planned maintenance	0.01%	N/A	0.01%	
Traffic signal assembly maintenance events	779	779	770	•

Seattle DOT's program is an example of good asset management planning for signals and ITS for two key reasons: (1) it includes a mature, regularly monitored and reported set of performance measures for ITS and signals; and (2) it relies on the performance measures to demonstrate progress to a public audience and make the case for funding, or at least make a clear link between investment in various assets and the performance outcomes.

Asset Maintainability Metrics—Highways England

In 2017, Highways England, a Government-owned company responsible for operating, maintaining, and improving England's highways and major roads, developed a guide to introduce performance requirements for its technology-related assets. To address asset failures, the agency introduced performance categories to group failures. Highways England requires that all major asset failures that interrupt operations are raised in its Fault Management System within the first hour of notification. For maintenance of traffic technology assets, Highways England defined three levels: first line (onsite repair), second line (at a technology depot or local office), and third line (at a repair facility or returned to the manufacturer, essentially needing to be shipped to a different location).

Highways England uses performance metrics (table 6) to track the maintenance cycles of assets and prevent recurrent maintenance needs due to temporary fixes. It also tracks downtime for technology devices (including both traffics signals and ITS) across three performance categories (urgent resolution faults, service affecting faults, and other faults). The agency only permits "clock stopping" when a third party or situation prevents prompt maintenance.

Table 6. Highways England maintainability metrics (selected items).

No.	Metric Description	Performance Category 1	Performance Category 2	Performance Category 3
1	Percentage of faults restored within 56 days.	100%	100%	100%
2	Percentage of faults restored within 168 hours.	100%	100%	–
3	Percentage of faults restored within 48 hours.	100%	100%	–
4	Percentage of faults restored within 24 hours.	100%	80%	–
5	Percentage of faults restored within 12 hours.	100%	60%	–
8	Number of Assessment Periods where no more than 4 faults can occur against any individual asset.	1 Assessment Period	1 Assessment Period	2 Assessment Periods
10	Average availability for all assets in the Performance Category within an Assessment Period.	99.99%	99.9%	97.5%

REPORTING FRAMEWORK FOR PERFORMANCE MEASURES

Conveying performance results is just as important as collecting actual data. Utah DOT populates a shareable and transparent dashboard based on its traffic signal performance metrics and targets. The dashboards are published to Utah DOT's website (Utah DOT 2019). Table 4 highlighted earlier in this chapter and figure 5 are two snapshots from Utah DOT's dashboard.

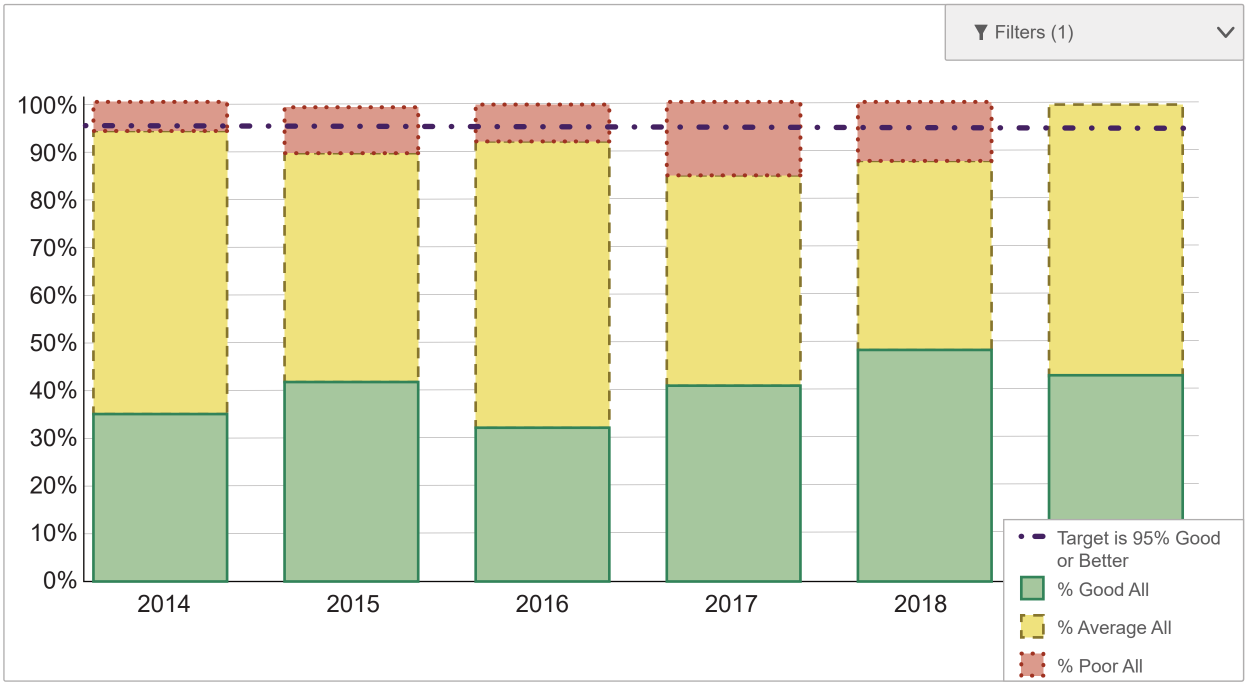

Figure 5. Graph. Statewide system condition of traffic signals for Utah Department of Transportation.
(Source: Utah Department of Transportation, 2019.)

Agencies should also look at using their management systems to create internal dashboards for varying levels of the organizations, from technicians to supervisors and managers (e.g., displaying maintainability metrics for supervisors, such as average time taken to address work orders, percent reactive versus preventive). Further, several agencies noted that using these measures can help make the business case for investment to leadership and stakeholders as well as improve internal processes and decisionmaking.

KEY ACTIONS

Key actions agencies can adopt or improve upon when implementing performance measures and target setting for traffic signals are listed below.

Develop and Set Asset Management Performance Measures/Targets

Identifying the right set of performance metrics for traffic signals is a critical, early-stage step. It helps drive the data collecting and ensures the agency is meeting its strategic and asset management objectives.

Key Steps:

- Review potential performance categories identified in this section (asset availability, asset reliability, and asset maintainability) and examples from other agencies.
- Determine which performance categories and specific metrics are most applicable to the agency, based on current needs, future demand, similar metrics captured for other asset classes, and current strategic and asset management objectives. Implementing performance measures should be a phased approach, starting with basic measures such as age and then visual condition. Such a phased approach is one way to ease into traffic signals performance management.
- Define the performance measures and set achievable targets based on operational and maintenance plans and available funding.

Develop Reporting Framework and Processes

The agency should develop a dashboard template and produce a high-level quarterly or annual asset management report with executive-level metrics and reporting on key benefits, outcomes, and impacts along with a summary of key initiatives and status.

Key Steps:

- Identify what data needs to be collected to adequately track the performance measures and targets selected (as discussed in chapter 3, Asset Identification, in this primer). This may include but is not limited to the age of the asset, a visual condition score (such as 1 to 5) captured regularly, or the amount of time it takes to address a failed asset.
- Start tracking data over time using the management system or tool. Once initial/sufficient data have been captured, identify which metrics are meaningful to various individuals (executive leadership, senior management, and supervisors) and how those data be best communicated to those types of individuals (e.g., a supervisor might like to see a dashboard in their management system with maintainability metrics, where a visual dashboard illustrating asset availability across the network may be more appropriate for executive leadership).
- Seek feedback from those reviewing reports (or dashboards) to determine if this is the right information and level of detail for those individuals; adjust accordingly.

CHAPTER 6. MAXIMIZING PERFORMANCE—LIFECYCLE PLANNING

Planning for the lifecycle of assets is a foundational principle of asset management. The FHWA encourages transportation agencies to develop and adopt asset management plans that enable them to meet the challenges of preserving their assets while optimizing their performance over asset lifecycles. The maintenance approach for each asset type may differ, depending on its risks and effect on the transportation network. Effective asset management planning is proactive. Rather than waiting for an asset to fail, requiring replacement or costly repairs, preventive maintenance and other proactive interventions may keep costs low and support better system operation (reduce delays).

FHWA TAMP Element: Lifecycle Planning, Risk Management (23 CFR 515.7(b)-(c))

Lifecycle planning is a critical component of asset management, but is most effective when part of a robust asset management program. Lifecycle planning is one of the emerging themes in traffic signals asset management. Lifecycle planning is a requirement for TAMPs. All major asset classes should have a lifecycle plan addressing future changes in demand, information on current and future environmental conditions, the management/ maintenance of the asset, and other factors that could impact whole of life costs of assets.

Every asset will eventually reach a point of failure, and this timeframe is often referred to as the *life expectancy* (National Academies 2012). Each asset may experience a different rate of deterioration. Figure 6 illustrates various deterioration rates.

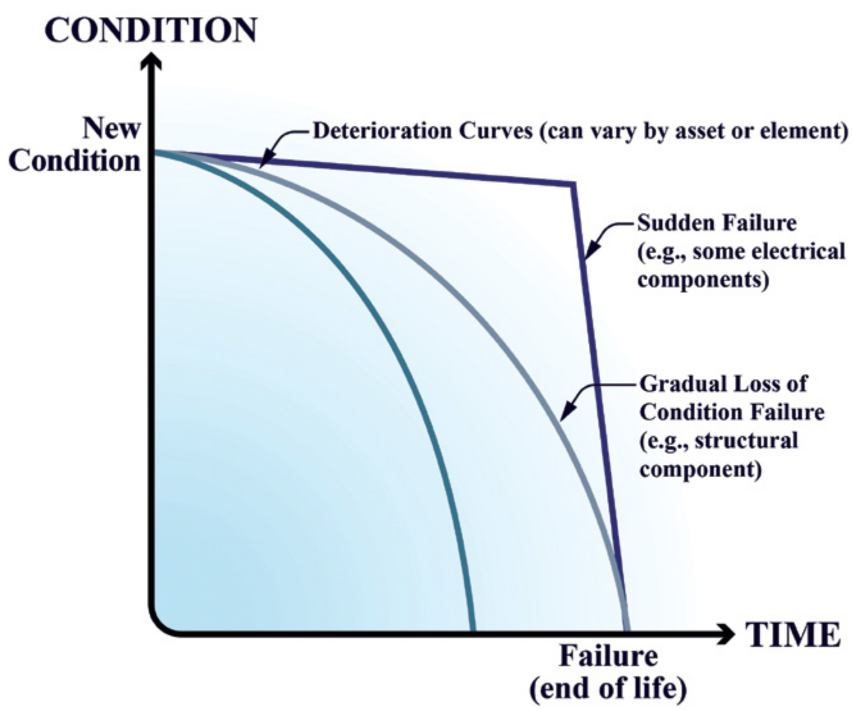

Figure 6. Graph. Asset deterioration curves.
(Source: FHWA.)

Assets (especially electronic assets) can fail at any time (sometimes unexpectedly). As an asset gets closer to the end of its life, the risk of failure increases. This increased risk creates uncertainty in decisionmaking and lifecycle planning.

Several key concepts that inform asset specific decisionmaking are as follows:

- ***Maintenance Management***—How maintenance decisions are made within an agency. The maintenance management approach influences the method to estimate the lifecycle cost of managing an asset over its whole life.
- ***Work Types***—The action taken as a result of a life-cycle planning approach. FHWA uses work type categories of initial construction, maintenance, preservation, rehabilitation, and reconstruction.
- ***Lifecycle Planning***—The overall process to estimate the cost of managing an asset class, or asset subgroup over its whole life with consideration for minimizing cost while preserving or improving the condition.

MAINTENANCE MANAGEMENT APPROACHES

With traffic signals, an agency may consider a range of maintenance management approaches, including the common approaches listed in table 7.

Table 7. Maintenance management approaches for traffic signals.

Approach	Description	Outcome
Condition-Based Maintenance Management	Maintenance activities are scheduled based on regularly monitored performance. Typically, used on assets with long asset lifecycles.	Approaches can lead to asset preservation.
Interval-Based Maintenance Management	Maintenance activities are scheduled at specific time intervals based on an analysis of asset performance. Used on assets with either short or long lifecycles.	Approaches can lead to asset preservation approaches.
Reactive Maintenance Management	Maintenance activities are performed in response to reported asset failures or events, such as a vehicle collision or component failure.	Requires repair/ replacement to return service.

Each approach listed in table 7 can be appropriate for certain assets. The following sections describe the approaches and their application.

Condition-Based Maintenance Management

Condition-based maintenance management involves regular monitoring of an asset to assess the point at which repair or replacement is required, as shown in figure 7. The cost to undertake inspections can be high and should be balanced with the associated risk of failure.

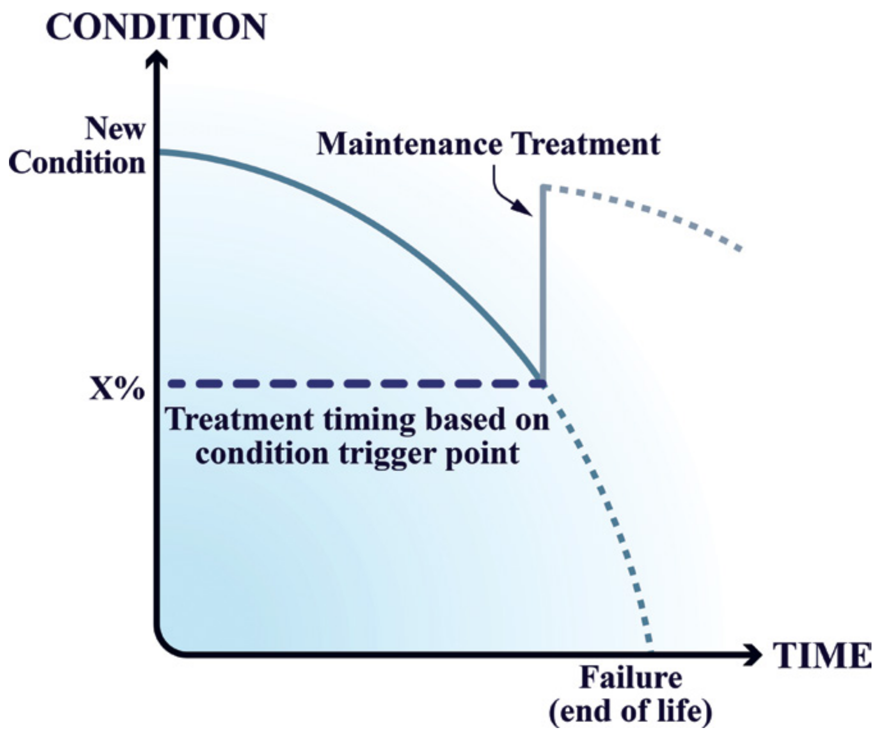

Figure 7. Graph. Condition-based maintenance management.
(Source: FHWA.)

For traffic signals, traffic signal poles should be inspected regularly because they are major supporting structures. Virginia DOT conducts a combination of maintenance management approaches for its traffic signals, including condition-based maintenance for its traffic signal structures.

Interval-Based Maintenance Management

Interval-based maintenance is commonly used for traffic signal assets, and it is a good starting point for planning and predicting needed repair or replacement. Once an asset reaches a specified age it is either repaired or replaced. The age at which an asset must be repaired or replaced varies (sometimes considerably) but this proactive approach reduces the likelihood of asset failure. Interval-based maintenance uses information on the age of the asset to assess the time to repair/replace. A decision on the best way to predict service life depends on the information available, knowledge of the product, and the time available to decide. This information may come from various sources, including the manufacturer, industry best practices, and the agency's own research. Interval-based preventive maintenance (figure 8) creates an opportunity for operations checks for traffic signals. Technicians may check the pedestrian timing as they check the pedestrian push buttons. They often check signal timing parameters, such as gap times and min and max green. In-pavement loop detectors are usually checked as well.

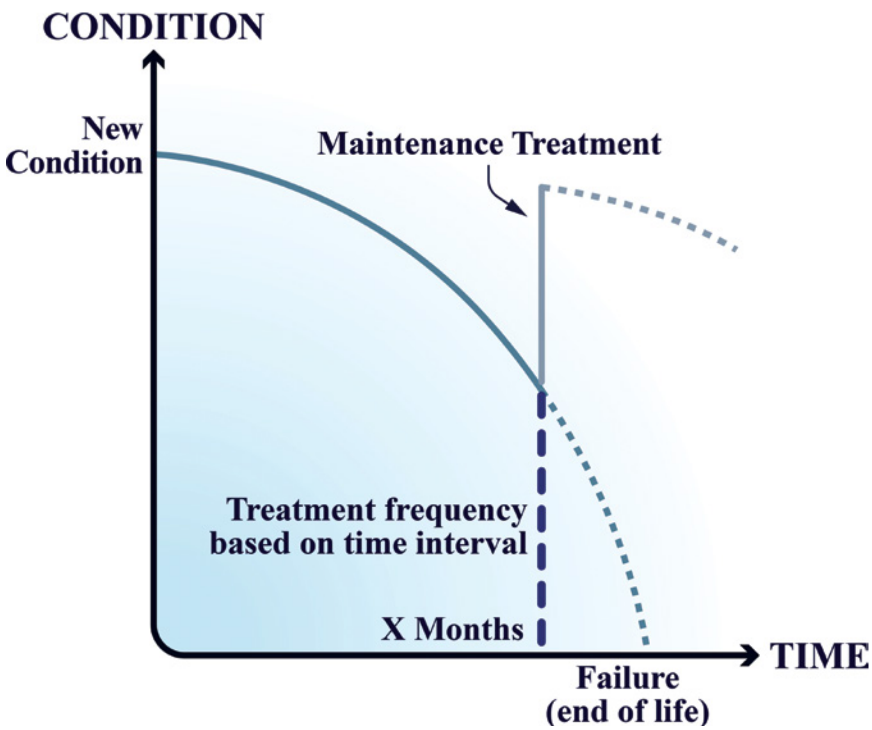

Figure 8. Graph. Interval-based maintenance management.
(Source: FHWA.)

Condition-Based Lifecycle Management—Virginia DOT

Virginia DOT classifies its traffic signals into two components: the traffic signal structure (what it defines as an ancillary structure) and the traffic signal head (the electrical and technical components). For the traffic signal structure, Virginia DOT assesses the condition of the superstructure (span wire and/or cantilever) and the substructure (foundation). The condition ratings used 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 similar to those defined by FHWA for bridge inspection. Signals are inspected for condition every four years. Figure 9 shows the condition of Virginia DOT's ancillary structures for three of the five rating categories.

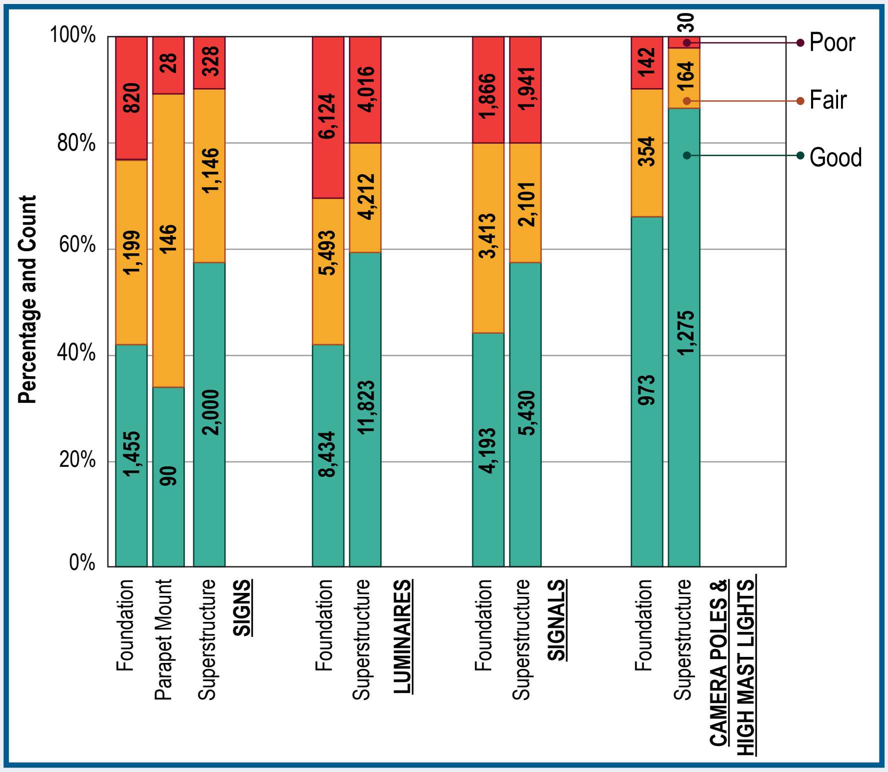

Figure 9. Graph. Virginia Department of Transportation condition of ancillary structures.
(Source: Virginia Department of Transportation, 2018.)

For traffic signal heads, the agency follows an interval-based approach. Information (based on industry standards and field subject matter expert observations) on the age, expected useful life, and recommended cycles of preventive maintenance and replacement for traffic signals is used to develop a maintenance management model that generates needs information. Investment activities for traffic signals include repair and replacement to restore a damaged or deteriorated asset to standard design, functionality, and capability.

Reactive Maintenance Management

When the information on an asset is limited, the risk of failure is low, or the cost to collect data (including condition) is high, then a reactive approach to repair and replacement may be appropriate. Although reacting to asset failure has the benefit of maximizing the life of the asset, from a risk perspective, this approach should consider the time required to repair the system and the impact of that down time. When deciding to take a reactive approach (figure 10), agencies should consider that traffic signal failures can introduce major safety and operational issues (i.e., signal goes into flash mode or goes dark) or less critical failures (i.e., system communications fails but has minimal impact on actual operations). A failure can be identified in a number of ways, commonly including through sensor detection or public complaints.

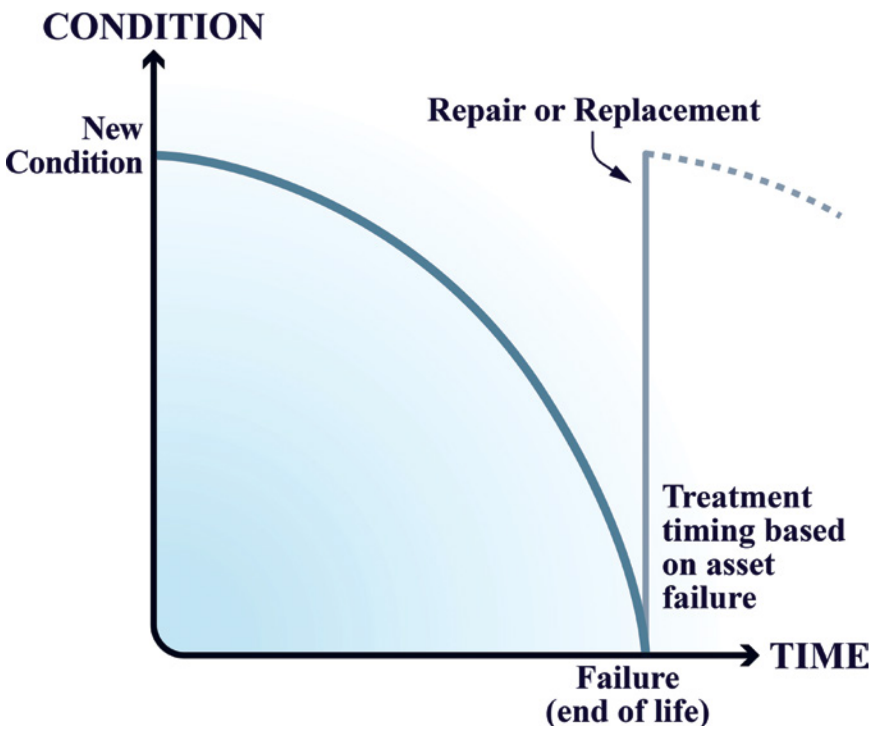

Figure 10. Graph. Reactive maintenance management.
(Source: FHWA.)

Predicting Performance of Traffic Signal Assets—Austroads

The Technical Supplement to the Austroads Guide to Asset Management provides a list of common approaches to predicting the service life of assets including:

- Manufacturers' performance data.
- Professional judgment of agency staff.
- Literature reporting service life experienced by others.
- Documented road agency experience: for example, historical databases or other records of asset performance and service life.
- Lifecycle cost analyses to compare the performance and costs of alternative components.
- Predictive models or management information systems to support the management of these assets.

This guide also provides an overview of likely failure modes, methods for predicting service life and the data required for monitoring. The performance prediction for traffic signals is provided in table 8.

Table 8. Predicting performance of traffic signal assets.

Asset	Asset Lifecycle (Physical) Performance "Failure" Mode(s)	Predictability of Physical Service Life of Asset	Data Required for Monitoring
• Traffic signals • Traffic sensing loops • Traffic signal controllers	• Lamp failure (end of globe life). • System failure due to damage/deterioration of controller. • Reduced conspicuity due to dirty lends. • Damage from vehicle crash or vandalism. • Technical obsolescence.	• Professional judgment based upon local experience, manufacturers' data on life of components and monitoring.	• Operation. • Power supply. • Power usage. • Condition and cleanliness.

RELIABILITY-CENTERED MAINTENANCE

Given the three maintenance management approaches previously discussed, agencies must decide which one is best for them. A reliability-centered maintenance (RCM) approach can be beneficial here. RCM is the application of engineering principles to manage the consequences of failure. The RCM process also invokes engineering reasoning to establish the appropriate maintenance tasks for a given asset. It can be used to select the preferred maintenance management approach for an asset. An example of this is shown in figure 11.

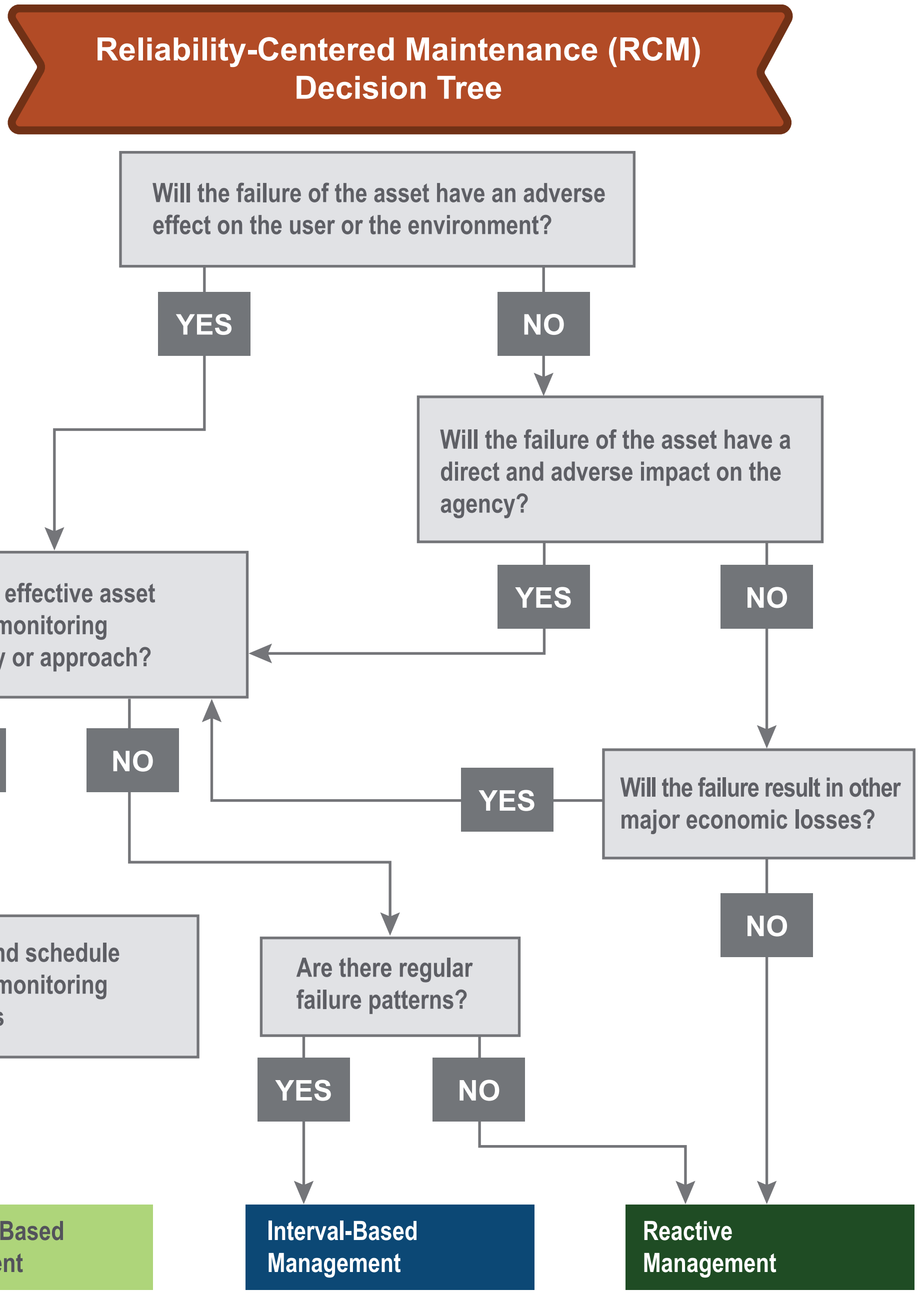

Figure 11. Flowchart. Maintenance Approach Decision Tree.
(Source: FHWA, 2019.)

The RCM process has been used in defense, airline, and mining industries to improve the reliability and cost effectiveness of maintenance activities. RCM is relevant to these industries because of the use of complex electronic and communication equipment that needs to work in an integrated manner.

The following discussion draws from an Austroads report, *Reliability-Centered Maintenance Strategy and Framework for Management of Intelligent Transport System Assets* (Austroads 2016), which further defines RCM and identifies key success factors, benefits, and acceptance of RCM approaches.

The basic steps of RCM involve a set of questions as follows:

1. Under what circumstance can an asset fail that may lead to major economic, environmental, operational, and safety costs?
2. What are the root causes of the failure?
3. Can the failure be viably managed through proactive maintenance? If yes, it is best to minimize the possibility of the failure through proactive maintenance techniques, including on-condition maintenance and preventive maintenance.
4. If proactive maintenance is neither technically nor financially feasible then identify the best alternative maintenance task, which could be a combination of tasks including the following:
    a. Unscheduled maintenance.
    b. Equipment redesign.
    c. Failure-finding tasks.
    d. Modifications to operating procedures.
    e. No scheduled maintenance (i.e., make no effort to anticipate).

As part of Austroads' RCM study noted above, a number of traffic signal assets were considered as case studies. A group of practitioners went through the RCM process for these assets. Table 9 illustrates some of the key findings, specifically in this case, for inductive loop vehicle detectors (as part of a traffic signal).

Table 9. Austroads reliability-centered maintenance process.

Item	Description
Component	Inductive loop vehicle detectors.
Function	To accurately detect and count vehicles as inputs to traffic signal control.
Functional failure	• The sensors are unable to detect vehicles. • The sensors are sending inaccurate readings.
Most prominent failure mode	• Pavement cracks or erodes to expose loop cables. Loop lifts up out of pavement and loop frequency changes, therefore loop cannot detect vehicles. • Loops exposed or poorly terminated due to incorrect installation.
Failure effect	• Vehicles are undercounted or overcounted, resulting in suboptimal signal control leading to longer delays at intersections. • Turning vehicles not detected and turning arrow not activated, resulting in long wait and increased risk-taking by vehicles.

Table 9. Austroads reliability-centered maintenance process (continuation).

Item		Description
Determine criticality	Failure consequence	Not severe to severe, depending on location.
	Likelihood	Most likely.
	Criticality	Critical (yellow).
List possible task (if applicable)	On-condition maintenance task	• Conduct on-condition survey and document level of pavement wear. • Inspect condition of surrounding pavement for water ingress, pooling water, and exposed loops. Repair pavement as required.
	Scheduled restoration/ replacement task	Restoration as part of pavement rehabilitation.
	Change operating procedure	Activate 'fail safe' mode whereby detector is left on if terminal fault is found in the loop/leads to over-counting, but at least signals change (turning arrow).
	Charge in commissioning (installation to site)	• Revise installation process to ensure loops are correctly installed, with no part of the loop protruding from the pavement. • Inspect commissioning immediately after installation, and periodically thereafter. • Document handover between installation contractor and service operation, including inspections. • Document correct termination techniques and ensure proper training of technicians.
	Equipment redesign	• Interrogate SCATS (or other traffic signal management system) counts for irregularities and reoccurring zero counts to identify failed loops. • Consider video-based detection.
	Call-out maintenance	Conduct call-out repairs as currently practiced.
Remarks		All of the above tasks should be implemented.

Obsolescence

Technology assets (including traffic signals) can become obsolete even if the asset is in good physical condition and functioning as designed. With rapidly changing technology and expectations of the traveling public, technological demands of the transportation system may exceed the asset's capacity to provide the necessary service.

For advanced technology that is commonly found in traffic signals assets, obsolescence is a challenge. For example, an asset can become obsolete if:

- It needs to be replaced due to other projects (e.g., road widening).
- The software or the product is no longer supported by suppliers, and software upgrades or replacement parts are unavailable.
- The cost to repair becomes greater than the cost for replacement (and often improved) products.
- The software is no longer compatible with new systems.
- New, adopted concepts cannot be supported (such as ATSPM or transit signal priority).

The challenge with obsolescence is that it is hard, if not impossible, to predict. It can shorten the expected life of an asset and mean that it needs replacement before it reaches the point of failure. Sometimes, upgrades in the asset or even software can have a net benefit to the mobility and reliability of the transportation system in addition to cost savings, even if the current setup is meeting the demands of the system. Agencies are starting to identify strategies and steps to better plan for obsolescence, which typically follows a risk-based approach:

- ***Asset Lifecycle*****—**Determine how long the asset should be sustained and operated, considering any major mid-life upgrades or replacements.
- ***Identify Components Most Likely to Become Obsolescent*****—**Breakdown the asset into its lowest maintainable units, or components. Most obsolescence issues are experienced at the component level.
- ***Develop Criteria to Assess Obsolescence Risk*****—**Identify various factors the agency can use to determine the probability of an obsolescence issue and/or the operational impact, if the component were to become obsolete. This might include number of manufacturers, access to software upgrades, and ease of replacement.
- ***Assess the Risk of Becoming Obsolete*****—**For each component, based on the criteria developed, assign a score (such as low, medium, or high) for both probability and impact and calculate an overall obsolescence risk score.
- ***Mitigation Strategies*****—**For those components identified as high obsolescence risk, determine appropriate mitigation strategies, such as design considerations, planned system upgrades, and partnership agreements with suppliers.

LIFECYCLE PLANNING

As defined in 23 CFR § 515.5*:*

> *Lifecycle planning means a process to estimate the cost of managing an asset class, or asset sub-group over its whole life with consideration for minimizing cost while preserving or improving the condition.*

The process of lifecycle planning considers a range of different maintenance management approaches to deliver the most cost effective solution throughout the life of the asset. Lifecycle planning identifies the cost and outcome associated with a range of maintenance management approaches. This information then is combined with:

- **Existing condition information.**
- A **deterioration rate for assets** that assesses how quickly the condition of an asset falls from one condition level to another. In an age-based model, this will purely be the time to move from one condition level to the next.
- **An analysis period** that is usually at least as long as the time from asset creation through to asset rehabilitation or replacement.

The FHWA publication *Using a Lifecycle Planning Process to Support Asset Management* (FHWA 2017) addresses developing an initial lifecycle planning process that satisfies the requirements of 23 CFR part 515.

Lifecycle Planning Model—Caltrans

The Caltrans TAMP has four primary asset classes: pavement, bridge, drainage, and Transportation Management Systems (TMS). California TMS assets include (but are not limited to): traffic signals, closed circuit televisions, changeable message signs, traffic monitoring detection stations, and freeway ramp meters. As shown in figure 12, California's lifecycle planning model for its assets is based on the costs and service life of different types of treatments (currently, for TMS assets, the "Fair" state is not yet applicable). This lifecycle planning model is founded on the principle of deterioration. Deterioration is the physical degradation of an asset because of a combination of factors, including age, construction materials, environment, accidental damage, and traffic load. A set of deterioration rates are determined for each asset type to account for expected future conditions.

Caltrans currently uses a TMS Inventory Database populated by district personnel to track all statewide TMS assets. This database provides information on system type, location, and installation date. Caltrans is developing strategies to better monitor the condition of the TMS network, such as strengthening collaboration with maintenance staff, which will enable a more responsive and efficient replacement process.

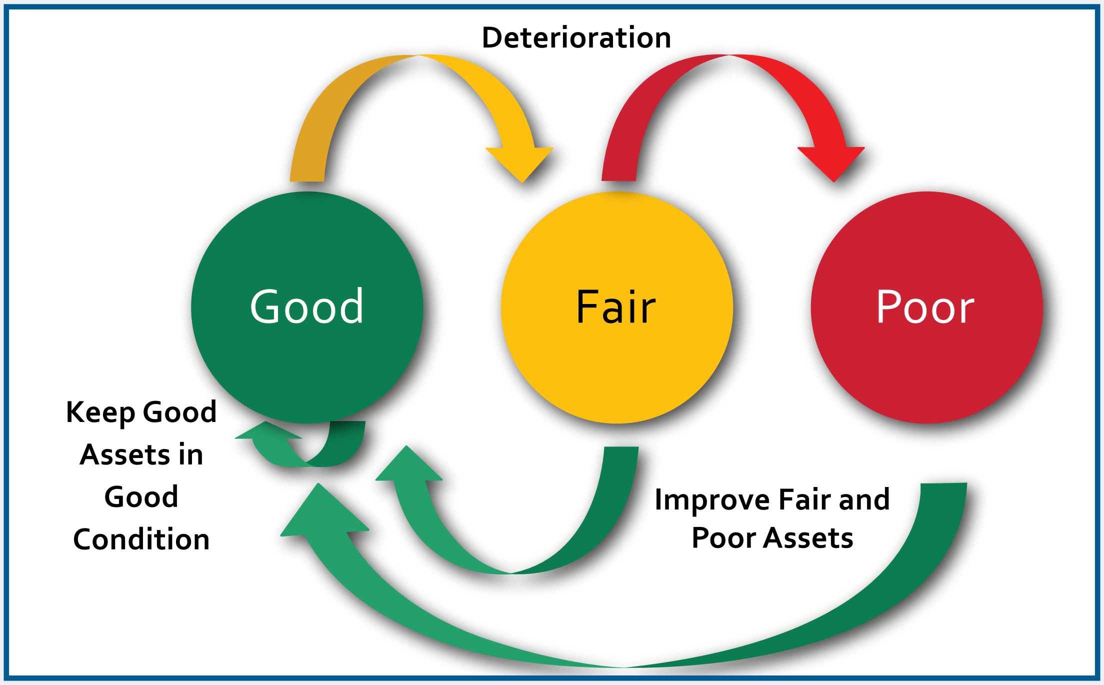

Figure 12. Diagram. Caltrans physical asset model for lifecycle assessment.
(Source: Caltrans, 2018.)

Lifecycle Planning for Traffic Signals—Minnesota DOT

Minnesota DOT included the following example of traffic signal lifecycle planning within its 2019 TAMP, shown in table 10. The traffic signal lifecycle analysis included four strategies:

- ***Strategy A:*** Included only reactive maintenance, with estimated maintenance costs.
- ***Strategy B:*** Consisted of three periodic inspections/preventive maintenance tasks, one each for operational, electrical, and electronic and were anticipated to reduce reactive maintenance costs by five percent.
- ***Strategy C:*** Consisted of replacing the electronics and the LED indications proactively on a periodic basis.
- ***Strategy D:*** Consisted of periodic structural inspection, which was anticipated to increase the expected life of the entire signal system from 30 years to 40 years.

Table 10. Minnesota Department of Transportation traffic signal lifecycle planning scenarios.

Treatments	Typical Costs	Strategy A Reactive Maintenance	Strategy B Preventive Maintenance	Strategy C Equipment Replacements	Strategy G Structural Inspection
Reactive Maintenance	$399	Annual	Annual	Annual	Annual
Operations Check	$74	None	Annual	None	None
Electrician Preventive Maintenance	$124	None	Every 3 years	None	None
Electronic Preventive Maintenance	$132	None	Every 2 years	None	None
Replace LED Indications	$20,000	None	None	Every 10 years	None
Replace Electronics	$30,000	None	None	Every 15 years	None
Structural Inspections	$1,000	None	None	None	Every 5 years
Expected Life	N/A	30 years	30 years	30 years	40 years
MNDOT EUAC Per Signal	N/A	$8,885	Add $23	Add $1,908	Sub $1,523

The agency's analysis indicated that the added inspections/preventive maintenance tasks cost more than they saved. Even if the inspections/preventive maintenance and replacement tasks had eliminated all reactive maintenance costs, it would still cost more than it saved. Although the inspections/preventive maintenance tasks of the middle scenario did not demonstrate benefit from a lifecycle cost point of view, the agency considers these efforts beneficial for operational and liability reasons. Conducting structural inspections lowered the equivalent uniform annual cost, saving more than it cost, by lengthening the time between total rebuilds of the signal system.

Building Information Modeling as a Tool to Inform Lifecycle Planning

One factor that can affect maintenance and operations of traffic signal assets during the lifecycle is how they are inventoried, particularly in capturing key attributes such as location data. Most agencies manage the inventory of signalized intersections or signal sites but not the individual components at the signal site (e.g., signal head, poles, and cabinet equipment). Critical data about traffic signal assets and components such as manufacturer details; type of device; warranty period of installed device; and maintenance recommendations, schedule, and activities are typically not captured after installation, but this information is important for operations, periodic maintenance and proactive workplanning.

Issues such as those stated above can be addressed by incorporating Building Information Modeling (BIM) processes, policies, tools and standards. BIM integrates many technologies and practices that bring digital tools and a data-centric approach for improving lifecycle delivery and management of highway assets. However, the approach for deploying BIM has been typically siloed, either within an organization's subunits or at the project level. Many State DOTs recognize the benefits associated with the bigger picture of BIM as a data-centric approach both for project delivery and asset management practices. BIM centers on the idea that data itself is an asset and that there are efficiencies to be gained when business silos are broken down so that data is accessible throughout a project and asset lifecycle.

Examples of BIM include:

- Contractors installing the traffic signal assets/infrastructure can be required to submit information about the installed (as-built or as-rehabilitated) assets in a prescribed format (typically a spatial data file with relevant attributes). These are referred to as "Employer Information Requirements" (EIR) in the BIM world and can be set up as a legal/contractual requirement. The data requirements can vary depending on the type of signal work (new installation, modification, rehabilitation, component replacement, in-house maintenance). In addition to contractors, the requirements can also be established for in-house maintenance crew.

- Tools such as mobile apps for traffic signal data collection can be deployed for meeting the EIR requirements at each stage of the lifecycle, especially when contractors or maintenance crews are changing any aspect of the installed infrastructure.

- Requirements used to build the computer-aided design (CAD)/BIM data model created with CAD or BIM standards during the design phase. To meet the EIRs, the as-designed models can be updated after construction to create the asset as-builts. Across the various design stages, construction and operation/maintenance stages—interoperability or exchange of these data models would ensure that information is constantly added to create and update the data model. In fact, information about the timing and cost of the installations for each asset should be captured in the model. Software systems used during design, construction and operation/maintenance phases should be able to accept models in open standards.

- Policies and processes should be in place to ensure that employees understand what data needs to be captured when and how.

KEY ACTIONS

Agencies can adopt or improve upon several key actions when working toward maximizing performance through lifecycle planning for traffic signals.

Understand the Outcome from Alternative Maintenance Management Approaches

Understand the outcomes of different maintenance management approaches to be able to demonstrate cost effective practices and inform investment strategy decisionmaking.

Key Steps:

- Understand the available maintenance management approaches (condition-based, interval-based, reactive) for each asset/component.
- Assess the lifecycle cost of different maintenance management approaches.
- Consider the risk that obsolescence introduces to different approaches.
- Use analysis to inform investment decisions (see subsequent section).
- Implement and continually revisit the selected management approaches. Consider how detailed asset information (e.g., age, condition, cost) may help influence lifecycle planning decisions and consider changes to asset inventory collection if appropriate.

CHAPTER 7. RESOURCE ALLOCATION—FINANCIAL PLAN, INVESTMENT STRATEGIES, PERFORMANCE GAP ANALYSIS

Financial planning can ensure that resources are appropriately allocated to maintain a state of good repair, achieve performance targets, minimize lifecycle costs, and address risks for different assets. Most agencies track the expenditure and performance of their high value assets by asset category, which varies between agencies, based on specific needs and operation. Part of financial planning includes compiling and analyzing historical information on asset condition, performance, and investments to support future projections.

FHWA TAMP Elements: Performance Gap Analysis, Financial Planning, Investment Strategies (23 CFR 515.7(a), (d)-(e), 515.9(d)(4), (d)(7)-(8), and 515.9(f))

This theme is extrapolated from three TAMP elements: financial plan, investment strategies, and performance gap analysis. By conducting a needs analysis based on the operations and maintenance of the assets and tying those inputs to its performance measures, agencies can begin to identify the effectiveness of their inputs as well as how to best align those resources. Undertaking this analysis draws heavily on lifecycle planning and risk management analyses. This emerging theme illustrates how agencies are conducting their needs analysis to fuel their investment decisions and convey those findings to their stakeholders.

INFORMING RESOURCE ALLOCATION

Lifecycle planning analysis can be used to inform decisionmakers of the:

- Cost to deliver a strategy—What is the cost to achieve desired performance outcomes?
- Outcomes for a funding scenario—What is the optimal performance outcome that can be achieved with a fixed financial budget?

Each different investment strategy will also result in a different risk profile or outcome. Each of these elements should be considered in resource allocation as figure 13 shows.

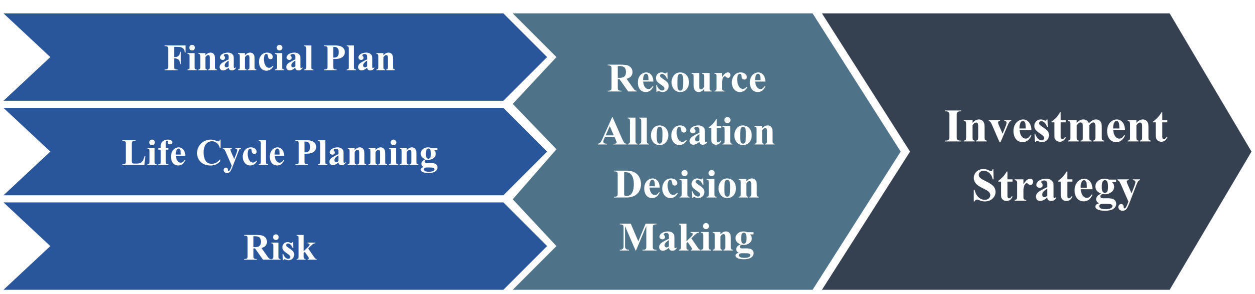

Figure 13. Diagram. Resources allocation decisionmaking process.
(Source: FHWA.)

The process of cross-asset allocation is only truly possible with a thorough understanding of the opportunity cost of investing in one asset over another. Agencies operate within constrained budgets. When decisions need to be made about allocating money to certain asset classes (e.g., traffic signals, ITS, pavements, culverts), decisionmakers should understand what will be achieved with the additional money spent as well as what objectives will be deferred by not investing in another asset class.

Traffic Signal Performance Projections—Connecticut DOT

Within its 2019 TAMP, Connecticut DOT presented a range of performance outcomes for varying investment scenarios, as shown in figure 14. Further, the agency's 2019 TAMP stated:

> *Performance projections for traffic signals were developed based on the current process for managing this asset. Each year, 100 traffic signals that have exceeded their service life would need to be replaced for this asset class to achieve its performance target in future years. Currently, the agency replaces approximately 60 signals each year under the annual traffic signal program that have exceed their service life. Additional traffic signals are upgraded each year under other highway projects and encroachment permits by developers, but some may not have reached their service life.*

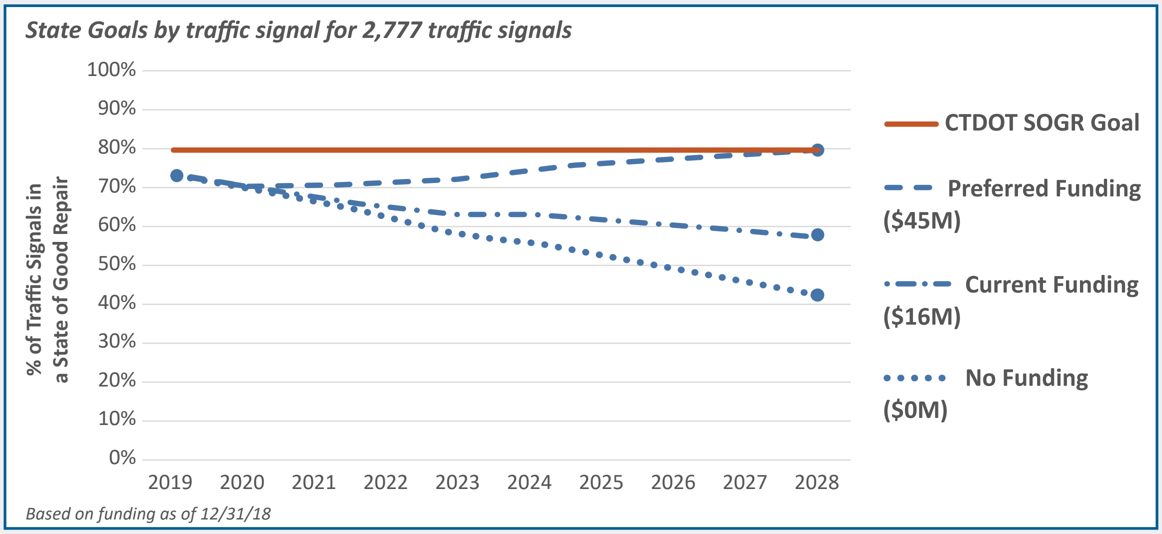

Figure 14. Graph. Connecticut Department of Transportation traffic signals performance projections.

(Source: Connecticut Department of Transportation, 2019.)

In addition to communicating condition outcomes, traffic signals have great potential to illustrate the benefit of additional investment, which can provide powerful support to specific investment strategies. Various agencies identified the tension between meeting mandatory requirements for pavements and bridges as well as funding needs for other asset classes including traffic signals. These agencies identified that, with the limited funding available for traffic signals, specific metrics such as the number of crashes and traffic volume, were used to prioritize investment allocations. This approach could be taken one step further to understand the impact of longer response times on traffic flow or even the increase in crash rates associated with traffic signal outages.

ASSET VALUATION

Asset valuation can be a powerful tool to communicate the outcome of different investment strategies or to track the impact of changing conditions over time. Key ways to address asset valuation include but are not limited to:

- ***Replacement Value*****—**Uses current market prices to rebuild/replace the asset.
- ***Condition Based Value (Depreciated Replacement Cost Method)*****—**Uses current market prices to rebuild/replace with depreciation to represent wear within expected life.

Several publications describe these approaches further, including the 2016 FHWA Guide, *Incorporating Asset Valuation into Transportation Asset Management Financial Plans*. Figure 15 is an extract from the 2016 Colorado DOT Asset Valuation Report to illustrate the value of traffic signals relative to other assets. As part of its Asset Valuation Report 2016, Colorado DOT developed a condition-based valuation for traffic signal assets. The condition assessment was age based (percent of asset life expectancy) multiplied by the replacement cost.

current value	$520.71 million
replacement value	$962.52 million
% value remaining	54.1%
unit cost	$500K / assembly
discrete quantity	1,852
unit quantity	N/A
average condition	68.0% age/life
condition distribution	

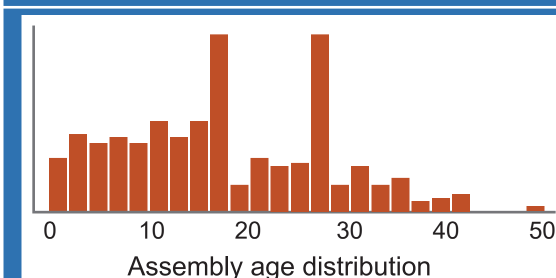

Figure 15. Diagram. Colorado Department of Transportation traffic signal asset valuation 2016.
(Source: Colorado Department of Transportation, 2016.)

COMMUNICATING AN INVESTMENT STRATEGY

Once an investment strategy is established, there should be clear communication to all stakeholders. This communication should consider the following audiences:

- ***Stakeholders***—Communication to internal and external stakeholders so that all understand expected outcomes that are planned.
- ***Those Responsible for Delivery***—So that they understand the targets that are expected to be achieved and how it is anticipated this will be delivered.

A TAMP can be used as a tool for communicating expected outcomes to stakeholders. California DOT (Caltrans) recently undertook a gap analysis as part of its TAMP development (Caltrans 2018). Table 11 in the example below indicates asset condition, currently for these assets the "Fair" state is not yet applicable.

Transportation Management System Assets Gap Analysis Outcomes—Caltrans

As part of its TMS and State highway system (SHS), which includes both traffic signals and ITS assets, Caltrans has identified a current gap in performance (percent in good condition, with good condition indicated by the asset being operational and not obsolete) and illustrated the expected 10-year outcome based on different funding scenarios. The gap analysis outcomes are shown in table 11.

Table 11. Caltrans asset gap analysis outcomes.

SHS TMS (assets)	Good	Fair	Poor
Current Performance	58.8%	N/A	41.2%
10-Year Expected (Post SB 1) Performance	90.0%	N/A	10.0%
10-Year Target Desired State-of-Repair Performance	90.0%	N/A	10.0%
Current Gap	31.2%	N/A	31.2%
10-Year Projected Gap	0.0%	N/A	0.0%

Traffic Signal Management Plans

The purpose of a Traffic Signal Management Plan (TSMP) within an agency is to connect the activities related to traffic signal design, operations, maintenance, and management with the goals and objectives of the agency. As such, a TSMP is a tool that documents activities (e.g., scope of proactive or reactive maintenance) so staff know exactly what they should do and when they should do it. As part of traffic signals asset management, the expectation is that a TSMP will:

- Document what traffic signal maintenance, operations, and design staff do, why they do it, and how their activities support the agency's goals and objectives.
- Provide a firm basis to support maintenance and operations as well as capital budgets.

- Facilitate succession planning and integration of new staff into the organization.
- Specify a logical framework within which staff training can be planned and organized.
- Help agencies become less dependent on key individuals, reduce ad hoc procedures and provide organization and structure for the agency's activities.

The details provided in a TSMP are often broader than maintenance and operations and help provide a link to planning and design decisionmaking. As such, a TSMP complements asset management and should be implemented in conjunction with traffic signals asset management.

KEY ACTIONS

Agencies can implement or improve upon several key actions when adopting resource allocation practices.

Develop a Process to Inform Resource Allocation Decisionmaking

Lifecycle planning, risk management, and a financial plan can guide decisionmakers on effective resource allocation approaches.

Key Steps:

- Provide information (e.g., investment scenarios and performance outcomes) for decisionmaking.
- Agree on a resource/investment approach.
- Set and communicate performance expectations based on investment approach.
- Identify opportunities to improve the decisionmaking process (e.g., additional information desired).
- Implement new decisionmaking process, through a phased or pilot approach (focus on one asset class at a time or a certain region).

Utilize Asset Valuation

Asset valuation can be a powerful tool to communicate the outcome of different investment strategies or to track the impact of changing conditions over time.

Key Steps:

- Understand the valuation approaches and data available to undertake an assessment.
- Complete a valuation of the assets.
- Monitor the change in asset value to inform investment decisionmaking.

Communicating Investment Strategies

Once an investment strategy has been agreed upon, there should be clear communication to all stakeholders.

Key Steps:

- Understand how best to communicate decisions to those responsible for implementation.
- Implement communication approach.
- Monitor implementation effectiveness and provide feedback.

CHAPTER 8. SUMMARY

Traffic signals are complicated assets critical to the daily functioning and safety of the Nation's roadways, and this primer provides information on applying TAM to traffic signals. The primer was developed based on national (and international) practices to demonstrate how key asset management concepts are implemented and applied to traffic signals.

The concepts discussed in this primer are organized into five themes for enhancing asset management practices and positioning a transportation agency to address traffic signals in an asset management plan, including in a TAMP, if desired. The themes are:

ASSET IDENTIFICATION

TAMP Element: Summary Listing of Assets (23 CFR 515.9(b)-(c) and (d)(3)).

Agencies should answer the questions, "what asset information do we need and why?" and "how do we properly use that information once we collect it?" Collecting the right information at the right time can then help agencies understand their assets' performance and make informed decisions about their long-term asset needs. This theme provides an overview of what type of asset information agencies should be collecting and why, for traffic signals.

Key Actions:

- ***Define and Collect Asset Attributes for Traffic Signals*—**Start collecting for the overall signal asset. Implement attribute data collection incrementally; that is, introduce new types of attributes over time and/or through a phased approach.
- ***Define and Collect Asset Attributes for Traffic Signal Components*—**Identify the most critical components of the traffic signal and again implement component data collection through a phased approach.

MANAGEMENT SYSTEMS FOR ASSETS

TAMP Elements: Summary Listing of Assets, Lifecycle Planning, Performance Gap Analysis, Risk Management, Financial Planning, Investment Strategies (23 CFR 515.7 and 515.17).

A robust management system can collect/store information and inform asset management decisionmaking. This theme addresses what type of systems could be used and how those systems should be implemented.

Key Actions:

- ***Identify Management System Requirements, Gaps, and Interfaces*—**Seek feedback from current and future users, and identify existing and future systems/interfaces, to develop a list of system requirements.

- ***Develop a Stakeholder Engagement Plan for System Implementation*****—**Consider steering committees, pilot implementation, and other techniques for a successful implementation of new processes.

PERFORMANCE MEASURES AND TARGETS

TAMP Elements: Asset Management Objectives, Measures and Targets for Asset Condition, Risk Management (23 CFR 515.9(d)(1)-(2) and (d)(6)).

Many traffic signals comprise different components with different life expectancies and conditions, and agencies often question how to best define the overall condition of these assets. This theme highlights some practices agencies are adopting to combat this challenge.

Key Actions:

- ***Develop and Set Asset Management Performance Measures/Targets*****—**Identify performance metrics to help drive data collection and ensure the agency is meeting its strategic and asset management objectives.
- ***Develop Reporting Framework and Processes*****—**Identify data to be collected, track data over time, provide it to those who are involved in decisionmaking, and seek feedback on how it informs behaviors.

MAXIMIZING PERFORMANCE—LIFECYCLE PLANNING

TAMP Elements: Lifecycle Planning, Risk Management (23 CFR 515.7(b)-(c)).

To provide a consistent, transparent, effective, and efficient approach to maintenance, an agency should understand the management approaches available. Further, a key consideration for traffic signals is planning for a time when an asset may become obsolete or unsupported. This theme looks at best practices for planning an approach to maintaining traffic signals.

Key Actions:

- ***Understand the Outcome from Alternative Maintenance Management Approaches to Lifecycle Planning*****—**Assess alternative approaches, information required, and benefit gained to select a preferred approach.

RESOURCE ALLOCATION—FINANCIAL PLAN, INVESTMENT STRATEGIES, PERFORMANCE GAP ANALYSIS

TAMP Elements: Performance Gap Analysis, Financial Planning, Investment Strategies (23 CFR 515.7(a), 515.7(d)-(e), 515.9(d)(4), (7)-(8), and 515.9(f)).

A lack of a formal funding needs assessment for traffic may be hampering efforts for long-term management of these assets. Asset management can be used to build a stronger understanding of the funding needs. Further, agencies are starting to use valuation-based approaches to communicate needs. This theme looks at recommended approaches to needs identification and communication of those needs for traffic signals.

Key Actions:

- ***Develop a Process to Inform Resource Allocation Decisionmaking*****—**Understand lifecycle planning, risk management, and financial plan to understand the most effective resource allocation approach.
- ***Asset Valuation*****—**Consider using asset valuation to communicate the outcome of different investment strategies or to track the impact of changing condition over time.
- ***Communicating Investment Strategies*****—**Once a resource allocation decision is made, make sure it is clearly communicated and understood by those responsible for implementation.

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