HANDBOOK FOR INCLUDING ANCILLARY ASSETS IN TRANSPORTATION ASSET MANAGEMENT PROGRAMS

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16. Abstract

This handbook presents a methodology that will aid highway asset owners and maintenance personnel with determining what assets, beyond pavements and bridges, are most important to support their agencies' missions and goals. The methodology prioritizes asset classes and identifies data related to those assets that best support a performance-based approach to managing the condition and utilization of those assets. The methodology is comprehensive, yet flexible, so it may be tailored to each agency's specific needs.

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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.

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EXECUTIVE SUMMARY

INTRODUCTION

This handbook will aid highway asset owners and maintenance personnel with establishing a prioritized approach for selecting assets beyond pavements and bridges to add to an asset management program in support of their agencies' missions and goals. The methodology presented prioritizes asset classes and identifies data related to those assets that best support a performance-based approach to managing the condition and utilization of those assets. Figure ES-1 introduces the framework described in the rest of this document.

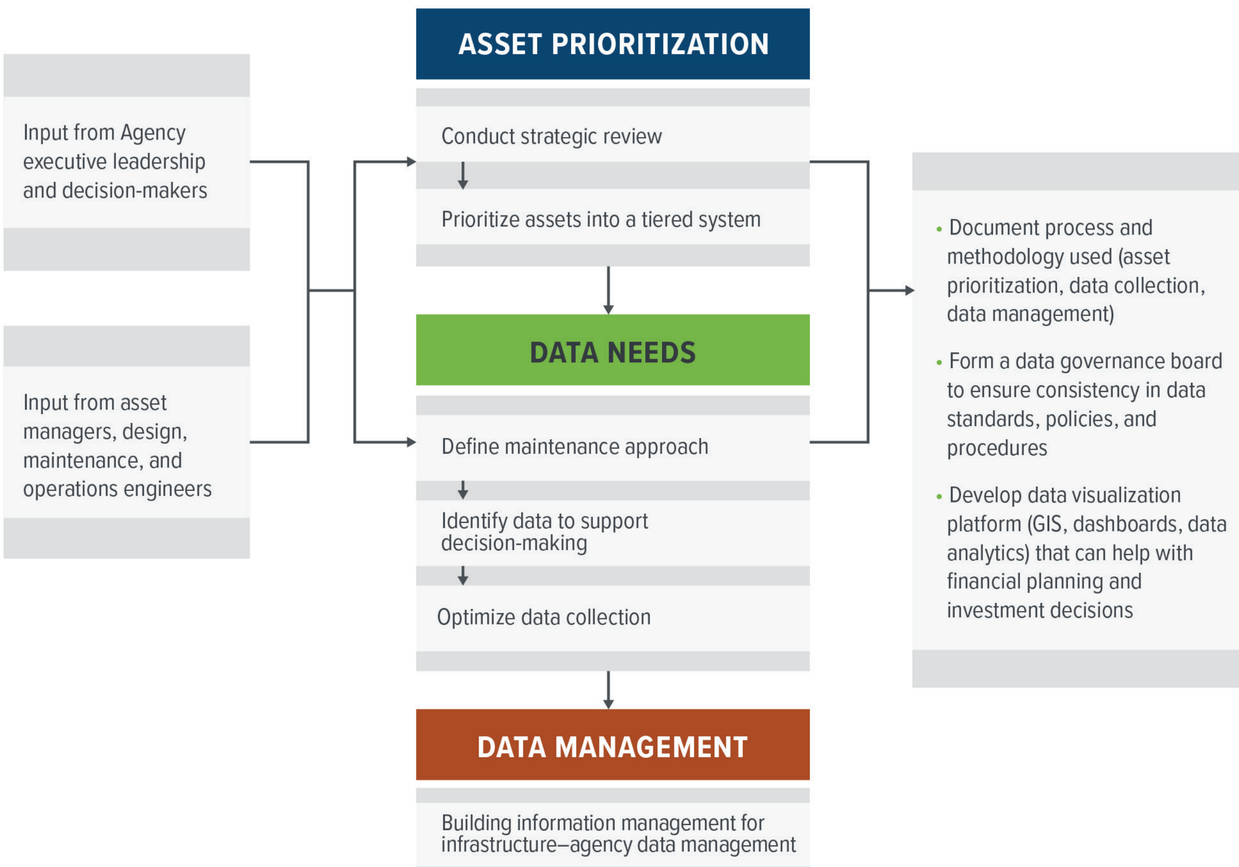


Figure ES-1. Chart. Framework for selecting assets and data for inclusion in an asset management program.

Managing Ancillary Assets Effectively

Transportation asset management (TAM) is a performance-based approach that uses agency goals and objectives to drive resource allocation related to the installation, maintenance, repair, rehabilitation, replacement, and operation of transportation infrastructure assets. TAM enables State and local transportation agencies to improve accountability, decision-making, and coordination between maintenance and capital programs and better manage the available funding. This allows agencies to better address all stages of an asset's service life, from initial construction/installation to rehabilitation/replacement.

Asset management is supported by the collection, management, and analysis of quality asset inventory and condition data. Asset management implementation is benefited by well-planned information technology (IT) systems that consider the decision-making processes that agencies use to keep assets operational and safe.

Highway agencies have traditionally focused their asset management implementations on pavement and bridge assets. Therefore, there is less information available about the ancillary assets (e.g., signs and signals, guardrail, culverts, lighting, pavement markings, retaining walls, etc.) that an agency maintains. To increase the amount of available information, many agencies have implemented maintenance quality assurance (MQA) programs that help maintenance personnel identify and prioritize maintenance needs. Other agencies have taken a further step by incorporating one or more ancillary assets into their transportation asset management plan (TAMP).

Introducing Performance-Based Management

Performance-based management allows for performance information to be routinely collected to monitor whether progress is being made toward agency goals and to communicate additional needs to key stakeholders and the public. Figure ES-2 presents four key elements an agency can use to implement performance-based management to manage its operational activities.

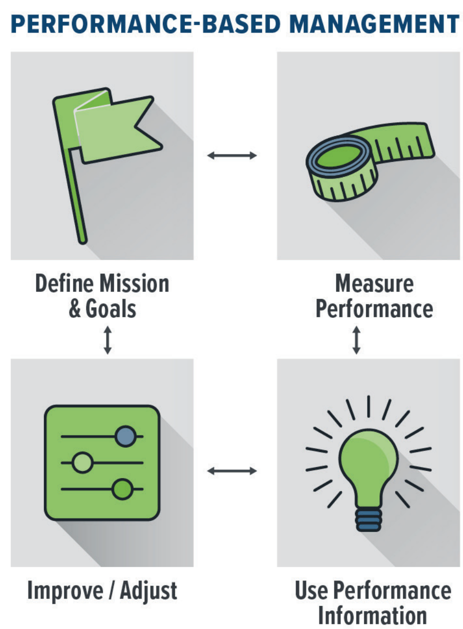


Figure ES-2. Graphic. Key elements of performance-based management (adapted from GAO 1996).

Goals and objectives are defined to enable the alignment of resources with priorities. A set of performance measures are established at each organizational level that align with the overall goals. Performance data is used to make decisions at all levels. Over time, performance-based systems integrate data-driven decision-making into daily operations of the organization. This is accomplished by balancing responsibilities with accountability and evaluating the process regularly to ensure that performance measures are driving the right decisions at the right time.

Benefits from a performance-based decision approach can include the following:

- Available funding is used to achieve agency goals and objectives.
- Resources are aligned with agency priorities.
- Agencies have the information needed to support funding needs.
- Planning and programming decisions are transparent.
- Agency accountability is improved.

AN OVERVIEW OF THE ASSET PRIORITIZATION METHODOLOGY

The methodology introduced in this handbook includes three primary components, each of which involves several activities. The process begins with activities associated with Asset Prioritization, including a strategic review and the development of prioritized asset tiers. The second part of the process involves a Data Needs assessment to determine what data needs to be collected to support agency decisions and how the data collection will be done efficiently. The final part, Data Management, includes activities to ensure that data governance is practiced so that the data remains useful. An overview of each activity is provided.

Part 1: Asset Prioritization

A Strategic Review to Evaluate the Need to Collect Additional Data

Figure ES-3. Graphic. Factors influencing the strategic review process.

An agency considering expanding its data collection practices to include ancillary assets may want to conduct a strategic review that accounts for agency policies, budgets, resources, and performance, as well as any legislated mandates and available technology related to the management of infrastructure or supporting assets. Figure ES-3 displays the components in a strategic assessment.

This strategic review process is typically driven by the following factors:

Risks—The potential impacts of uncertainty on agency objectives.

Changes—New organizational modifications or technical advancements that make new processes possible.

Gaps—Disparities between existing and desired management practices.

Prioritizing Asset Classes

Limited resources and budget constraints force agencies to make difficult decisions regarding resource allocations. Thus, agencies looking to expand their asset management programs to include additional information need a means of determining the benefits and costs associated with system development, data collection, and data management.

A seven-step process (figure ES-4) was developed to help agencies prioritize their assets into tiers. The process involves all business units that have a need for asset data or have a role in collecting and managing asset data. These seven steps fit under the "Asset Prioritization" process shown as part of the overall methodology summarized in figure ES-1.

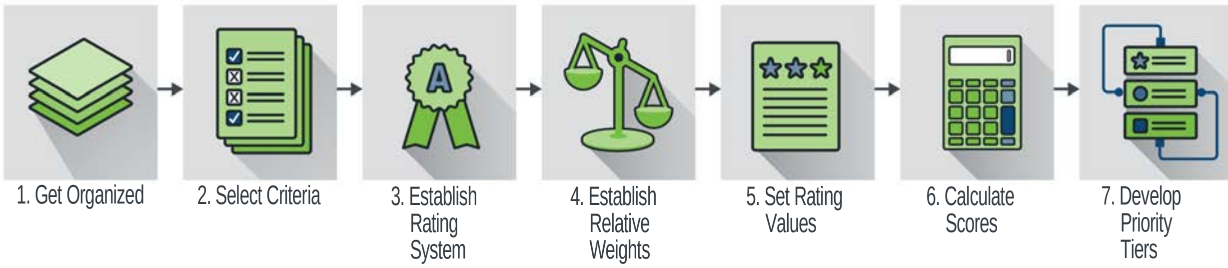


Figure ES-4. Graphic. Asset tier prioritization process.

STEP 1: GET ORGANIZED

A project team that represents all business areas with a need for information on assets included in the prioritization effort should be assembled. This commonly starts by identifying a champion, or team leader, who can communicate the vision for the effort to the full team and ensure that the effort is working to maximize value for the whole agency. A project manager should also be identified, either formally or informally, to ensure the team members are participating as needed and the work products are developed on time. After the leadership is in place, the remaining team members should be identified from stakeholder groups, both internal and external to the agency, who have an interest in using, managing, or collecting information about the assets.

This step is key to establishing the scope of the effort, identifying leadership and roles, identifying the needs of each business unit and defining a list of asset classes to be considered in the prioritization process.

STEP 2: SELECT CRITERIA

The prioritization process begins by establishing criteria that can be used to rate each asset class. Since the result of the prioritization process should help the agency fulfill its mission and goals, the criteria should reflect factors that are important to the agency, such as:

- The value of deployed inventory or the amount spent to maintain the asset class.
- The amount of external influence on managing the asset class.
- The urgency in addressing repairs to the asset class.
- The potential impact to the agency if the asset class is not formally managed.
- The amount of effort and cost to collect asset inventory and performance data.
- The agency’s readiness to use the data to drive decisions.

STEP 3: ESTABLISH RATING SYSTEM

Once criteria have been selected, it is important to establish a means of rating each criterion. The simplest means of rating objectively is to select a numeric scale. It is recommended that scales of either 1 to 5 or 1 to 10 are used and that the same scale is used for all criteria. However, some criteria cannot be rated objectively in this way. In addition to the numerical scale, some criteria maybe considered as yes/no. Other criteria may be more subjective in nature.

STEP 4: ESTABLISH RELATIVE WEIGHTS

Weighting criteria allow agencies to consider the relative importance of different criteria. Weighting can only be used for criteria that have been assessed using a common numeric scale. Criteria evaluated based on yes/no or subjective means are not appropriate for weighting. Care should be taken in establishing weights, and agencies may want to use an iterative process of adjusting weights after the development of a prioritized list of assets. NCHRP Report 806, *Guide to Cross-Asset Resource Allocation and the Impact on Transportation System Performance* (NCHRP 2015b), provides information on several methods for establishing weights.

STEP 5: SET RATING VALUES

Once the evaluation criteria have been selected and relative weights have been established, the prioritization team can begin the process of rating each asset according to each criterion. It is recommended that the scores be developed through one or more workshops during which scorers work together to develop a single priority score for each asset class. This approach allows individuals to provide input to the decision and work to build a consensus for each score. If necessary, survey tools or web meetings can be used to gather scores.

STEP 6: CALCULATE SCORES

Once all criteria have been rated, the raw priority scores are calculated by multiplying the rating for each criterion by its weight. The final score for the asset class is the sum of all rating-weighting products, as shown below:

$$\begin{gathered} \textit{Final Score} = (\textit{Rating } 1) \times (\textit{Weight } 1) + (\textit{Rating } 2) \times (\textit{Weight } 2) + \ldots \\ + (\textit{Rating } n) \times (\textit{Weight } n) \end{gathered}$$

This final score, based on the objective criteria, can be used to produce an initial ranked list of asset priorities, which is refined into prioritized tiers in step 7.

STEP 7: DEVELOP PRIORITY TIERS

This step combines the information from Steps 1 through 6 to form the agency's final recommendation for expanding the asset classes included in its TAM program.

A tiered methodology recognizes that initial priority scores are just one set of inputs into the final decision as to which assets to include in a new or expanding asset management program. Additional considerations for data collection and available resources will also factor into these decisions. Figure ES-5 is an example that illustrates how a ranked order list can be converted to a set of prioritized tiers.

The first time an agency completes this process, the list of priority tiers may not be fully informed of the costs associated with data collection and management. Those costs cannot be accurately established until a data needs evaluation has been performed. If the evaluation results in major changes to the assumptions used in rating the asset criteria, the agency may want to repeat the prioritization process using the estimated data collection and management costs.

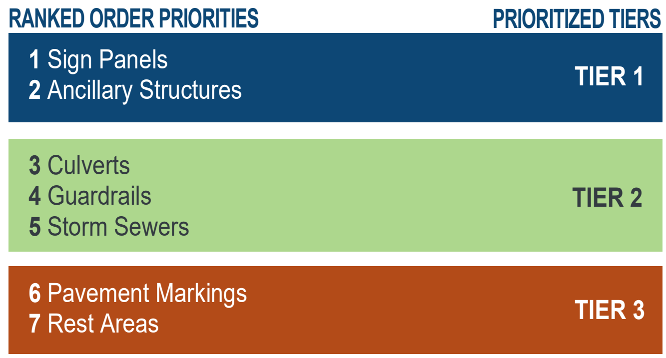


Figure ES-5. Graphic. Example of ranked order priorities used to establish prioritized tiers.

Part 2: Data Needs

Identifying and Selecting Data Needs

Agencies should collect, store, manage, and analyze large amounts of data in an effective and efficient manner to support asset management. This section outlines the activities associated with determining the data used to support performance-based management decisions for ancillary transportation infrastructure assets. The process described in the following paragraphs uses reliability-centered maintenance (RCM) to determine whether an asset is better managed using a condition-based, interval-based, or reactive maintenance strategy.

Data Needs to Support Decision-Making

Quality asset data are vital in making effective planning and investment decisions. Data may be considered essential, meaning that they include basic data attributes that help execute maintenance activities, or desirable, meaning that they support the maintenance program but is not essential. The quality of either type of data is important because the data serve as the basis for establishing maintenance budgets and tracking maintenance activities.

Data Collection

The development of an asset inventory is the first step in establishing a strong asset management program, and good data collection aids in making sound investment decisions. The three main data collection techniques used for collecting transportation asset data are manual data collection, photogrammetry, and mobile LiDAR (light image detection and ranging). Figure ES-6 summarizes and compares the key considerations in selecting the most suitable data collection technique.

The final selection of an approach to collecting asset inventory and condition data should consider the following:

- The ability to see the asset from the roadway.
- The level of accuracy used to make decisions.

- The exposure of the work crews to traffic.
- The way the data will be used.
- The resources available.
- The ability to collect the data as part of other data collection efforts.

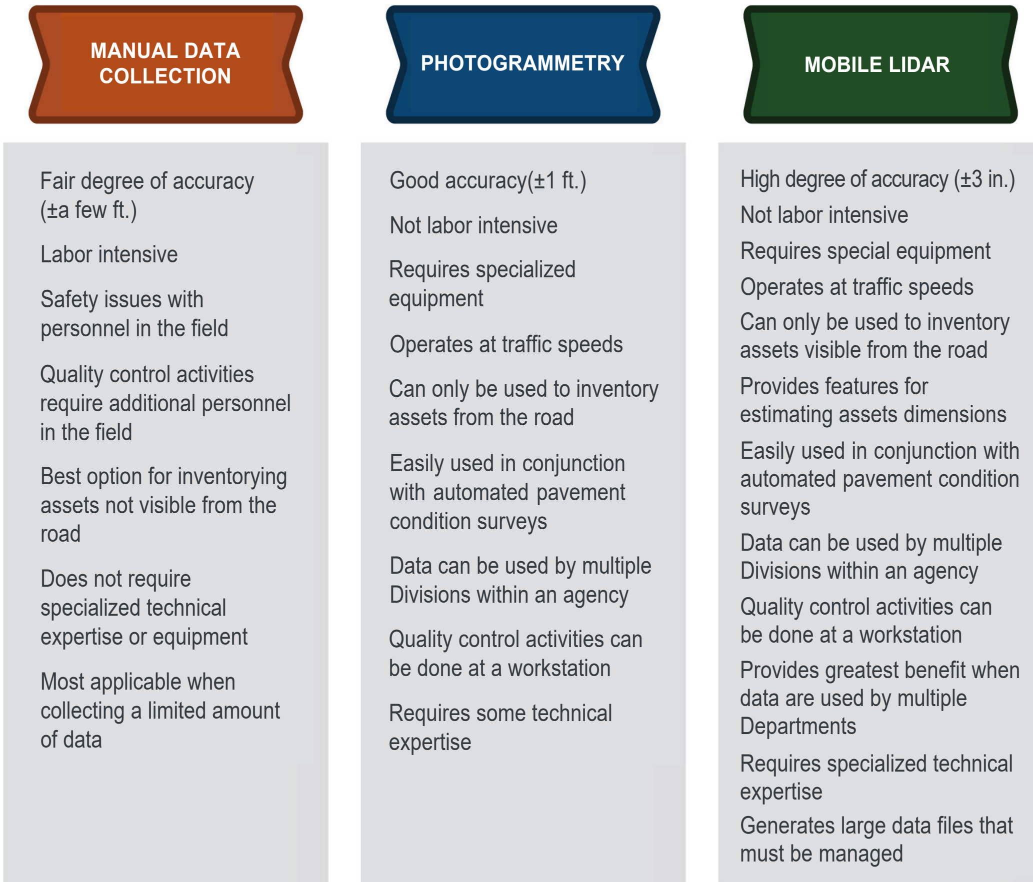


Figure ES-6. Graphic. Characteristics associated with the three main types of data collection (adapted from Zimmerman and Manda 2015).

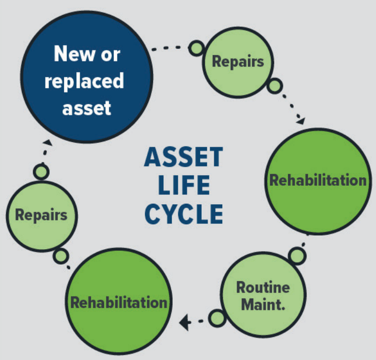
Part 3: Data Management

Definition of Building Information Management for Infrastructure

Chapter 5 presents the concept of building information management (BIM) for infrastructure. BIM for infrastructure is a philosophy and strategy of organizing, sharing, and connecting all agency information, including assets, and how an agency can manage assets through the entire life cycle.

BIM for infrastructure is a philosophy of information management that provides a framework for data integration of the agency's different business systems. It can form a reliable basis for managing assets during the entire life cycle, or from conception to demolition, of the asset. The goal of BIM for infrastructure is to manage all agency data, including asset data, to achieve accessible, accurate, and authoritative information. Asset and agency information that is organized and shared allows an agency to effectively manage assets during their entire life cycle while driving innovation to produce significant cost and time savings. Integration ensures that limited funding is allocated based on both engineering judgment and the best available information. Wise data-driven decision-making will stretch funding and resources and improve transparency.

BIM for infrastructure involves the processes related to the generation and management of the physical highway infrastructure and functional characteristics (financials, plan sheets, construction as-built plans, specification, etc.) in a digital format. It consists of data sets and files that can be extracted and exchanged to support decision-making regarding the department's infrastructure in general or for specific assets. BIM for infrastructure supports the transition from incomplete asset inventories and standalone silos of information to complete authoritative statewide inventories. The shared information may then be used by all affected parties for a wide range of purposes, including planning, environmental assessment, surveying, design, construction, maintenance, asset management, and risk assessment.



LIFE OF THE ASSET

CRADLE TO CRADLE

Example: Guardrail/Attenuator

- Planning—roadway characteristics, funding
- Design/Construction—location, type, specification, costs
- Maintenance—up-to-date inventory, treatments and costs
- Safety—crash history, analysis results, and performance data
- Benefits—Agency manages the assets with all available information

Figure ES-7. Graphic. Data for cradle-to-cradle asset management.

Integrated Maintenance Approach

LIFE OF THE ASSET—CRADLE TO CRADLE

Agencies plan, design, construct, and maintain assets in a continuous cycle, from "cradle to cradle." The agency can better manage individual assets or the entire inventory if data is shared across the life cycle from the original long-range statewide transportation plan to design and finally to maintenance. For example, safety, maintenance, and design units may have a need for information about the agency's guardrail. Shared information should include as-built plans, specifications, inventory, and costs. BIM for infrastructure and the cradle-to-cradle concept is illustrated in figure ES-7, which represents a typical transportation agency and the different types of data used throughout the agency.

BIM FOR INFRASTRUCTURE CENTRAL DATA HUB

The data hub is a key feature of the BIM for infrastructure concept. The data hub is illustrated by figure ES-8. It is a central repository for agency data that improves accessibility and the ability to share authoritative, trusted information.

Figure ES-8 demonstrates how the central data hub serves to support cradle-to-cradle asset management. The figure represents a typical transportation agency and how it might improve connectivity and commonality with its asset data. The outer circle represents the four primary functions: programming, project delivery, operations, and comptroller and performance. Each middle circle represents a specific agency division such as design, planning, or maintenance. The diagram illustrates how each division contributes to the total product of an agency, from planning to project development to asset management and operations. Each group produces and consumes data daily. The goal of the agency in applying the BIM for infrastructure concept should be to share authoritative information.

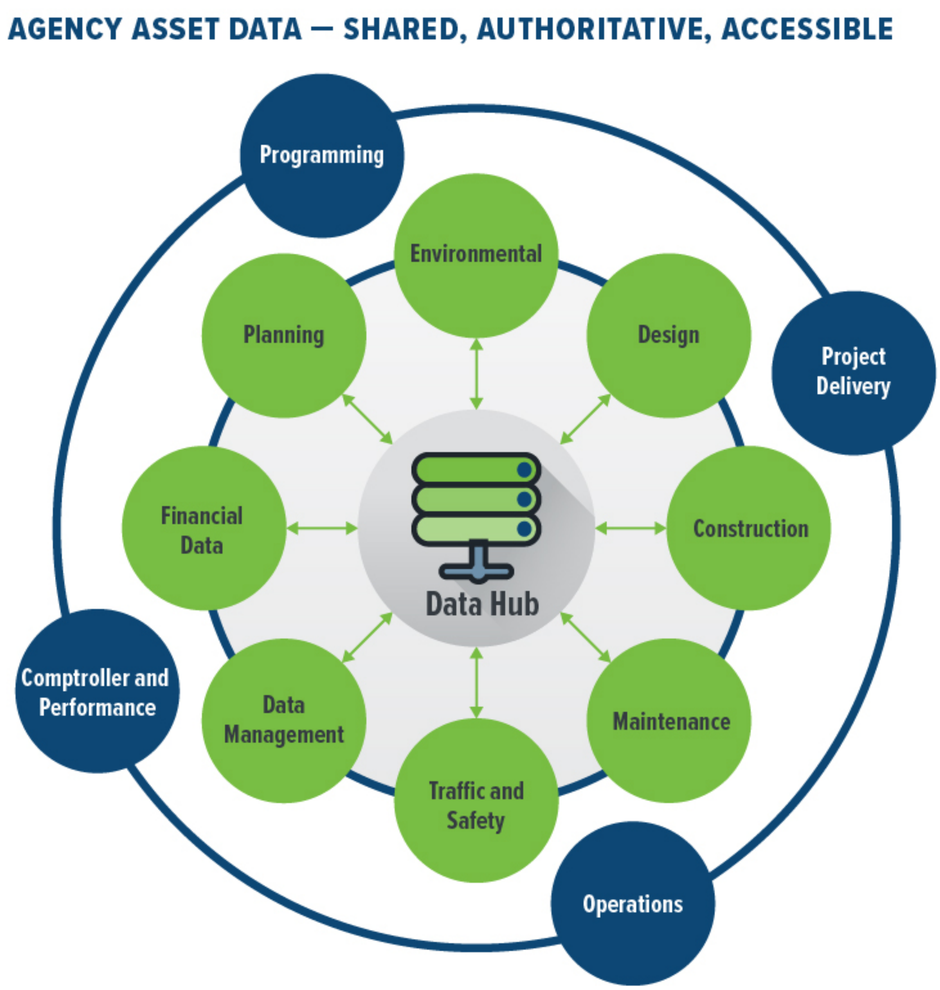


Figure ES-8. Graphic. BIM for infrastructure central data hub.

BIM for infrastructure is an evolving practice that requires years to implement. Figure ES-9 provides an overview of recommendations for effective BIM for infrastructure implementation.

VISION — DEVELOP AN OVERARCHING VISION FOR BIM

VISION — Develop an Overarching Vision for BIM

- Manage assets from cradle to cradle
- Establish a holistic approach to managing agency data: inventory, finance, project, and operational

GOALS — Set Agency Goals

- Strive to be wise stewards of public investments
- Provide transparency in the allocation of limited resources to achieve the greatest benefit
- Establish a single authoritative source for each data element
- Break down silos

MISSION — Articulate a Clear, Unambiguous Statement

- Track asset from planning, design, build, maintenance, to operation

STRATEGIC DIRECTION — Develop High-Level Implementation Strategy

- Provide easy access to quality, map-displayed data
- Create a central data hub
- Create common linear reference system
- Develop data management, governance and interoperability processes and standards
- Evaluate existing data collection approaches for fit in the envisioned BIM framework and develop action plan for any modifications needed to current practices and protocols

TACTICAL — Develop Implementation Strategy

- Integrate databases
- Create data dictionaries — definition of assets and attributes
- Determine critical (commonality) asset data to be tracked by all divisions
- Determine storage — on premise servers v. cloud-based
- Determine access — desktop v. web for public and internal users

TRANSFORMATION OF AGENCY CULTURE

- Identify champions from Executive Branch, Division Management, and Information Technology (IT)

COMMITMENT

- Dedication: agreement within agency, resources, financial

AGENCY DATABASE STRUCTURE — Independent Business System Evolution

- Understand different needs for timeliness, specific data elements, and levels of sophistication
- Unify to a common linear reference system
- Find opportunities to use the same data for multiple purposes
- Identify risks related to database implementation

CHALLENGES

- Change the culture of siloed divisions
- Create a culture of collaboration
- Promote trust

Figure ES-9. Graphic. Recommendations for BIM implementation.

Keys to Success

Table ES-1 summarizes the key factors that will help ensure success in each of the key topics discussed under the methodology summarized in this handbook.

Table ES-1. Keys to success.

TOPIC AREA/ACTIVITY	SUGGESTED PRACTICES
Managing ancillary assets effectively	• Use performance measures to define and improve agency goals. • Strategically recognize risks, changes, and gaps.
Selecting assets for inclusion in asset management systems	• Include all business units to determine criteria ratings and weights to prioritize assets in tiers. • Document results and update periodically, especially upon completion of data collection and management.
Identifying and selecting data	• Establish a realistic understanding of the intended function of the asset, failure modes, maintenance approaches, and consequences/impacts of failure prior to data collection.
Managing asset data	• Recognize areas of data integration across the agency using BIM and recent technologies to complete asset inventories.

CHAPTER 1. INTRODUCTION

ADVANCING ASSET MANAGEMENT

TAM is becoming widely accepted as an approach for managing transportation infrastructure assets. TAM is intended to increase the accountability and transparency of agency decisions, focus funds on agency priorities, and improve decision-making through performance-based planning and programming.

As a performance-based approach to managing asset conditions, TAM depends on the availability of quality inventory and condition data, as well as tools for evaluating the impacts of different investment strategies on network-wide conditions. Implementing TAM requires a significant investment in developing IT systems, as well as collecting, processing, and managing data. For that reason, highway agencies have traditionally focused their efforts on pavement and bridge assets. The availability of asset inventory and condition information for ancillary highway assets (such as signs, guardrail, culverts, lighting, pavement markings, and retaining walls) is less common.

Federal statute (23 CFR 119(e)) and regulations (23 CFR 515) require State Departments of Transportation (DOTs) to develop TAMPs for pavements and bridges on the National Highway System. Although the Federal regulations are focused on managing pavements and bridges on the National Highway System, many State and local transportation agencies are implementing TAM on a network-wide basis as a means of improving coordination between their maintenance and capital programs so they make better use of available funding.

Many transportation agencies have collected part of the data necessary to manage ancillary assets, but are missing complete inventories, conditions, or analysis tools to implement risk-based TAM fully. Agencies that have implemented a performance-based management framework for some classes of assets may wish to expand their asset management program to include others. To date, there has been no comprehensive methodology for transportation agencies to use regarding which additional assets should be included in their asset management programs and what data is necessary to manage those assets. The FHWA initiated a research effort in 2016 to address that gap, and this handbook represents the results of that research effort.

PURPOSE

This handbook has been developed to assist State and local DOTs and other highway owners in determining what assets and asset-related data—beyond pavements and bridges—are most important in supporting agencies' overall missions and goals. The methodology presented is comprehensive and flexible so it may be tailored to each agency's specific needs. This handbook presents general information on asset management and performance management. While the approaches discussed in the handbook may be helpful to those implementing the Federal requirements, the handbook is not intended to address the Federal requirements or how to meet those Federal requirements

PROCESS OVERVIEW

The methodology applies a performance-based management approach to determine which asset information will be most useful to support decisions related to the installation, maintenance, improvement, and replacement of ancillary assets. Performance-based management is a framework that identifies measurable criteria that can be used to track progress toward achieving the agency's overall mission and goals. Chapter 2 provides an overview of performance-based management and describes how this approach can be applied to the management of asset conditions.

A methodology for selecting assets and data for inclusion in TAM systems is presented in two parts: Asset Prioritization and Data Needs. Asset Prioritization is presented in Chapter 3. This chapter recommends agencies use a top-down view of the agency's mission and priorities to determine a ranking for adding assets to their TAM program to achieve their desired goals. Chapter 4 presents a process for agencies to determine which data elements are necessary or desired to support management decisions throughout the life of each asset.

> **ACRONYMS OF INTEGRATED PROCESSES**
>
> **BIM:**
> Building Information Management
>
> **CIM:**
> Civil Integrated Management

Asset data supports many different transportation objectives, including safety, operations, and system efficiency. This means that many different offices or business units within each transportation agency need to collect, store, analyze, and report on asset data. Chapter 5 provides an overview of integrated data governance and management, which can help agencies ensure they are collecting and managing data in a way that best supports the needs of all users. The term used to describe this integrated approach is *building information management for infrastructure*, or BIM for infrastructure. This term is similar to *building information modeling*, which is used to describe standardized approaches to data structures used in many industries across the world, from manufacturing to the vertical building industry's construction and management fields.

The term *civil integrated management* (CIM) has gained use at transportation agencies in the United States to describe strategies for sharing all highway information and knowledge across all divisions. CIM has been gaining popularity at transportation agencies to describe a means of standardizing data sets related to highway design and construction activities. FHWA has chosen the term *BIM for infrastructure* to indicate the connection of this approach to building information modeling, but the term *management* is used in place of modeling to describe how this approach not only leads to integrated data sets but also facilitates integrated management practices throughout an asset's life cycle from planning through design and construction and finally to highway operations.

Figure 1 describes how Connecticut DOT has planned out an integrated data model based on BIM for infrastructure and is using that to incorporate additional assets into the agency's asset management program.

Figure 2 represents how the two methodology components and data management work together to support performance-based management of ancillary assets.

Each of the individual components depend on input from key internal and external stakeholders to identify what information is most critical to making management decisions. Another commonality in all three components is that they use documented and shared processes, organizational structures, and plans. Documented processes support coordination between business units to ensure all business needs are met and efforts are not duplicated.

CONNECTICUT DEPARTMENT OF TRANSPORTATION

The Building Information Management (BIM) for infrastructure goal at Connecticut DOT is to have inventory at the user's fingertips that is accurate, authoritative, and accessible. Connecticut's case for the BIM for infrastructure effort is being driven by safety and design engineers' need for accurate asset inventory. During a typical year, Connecticut may have 100-150 ongoing capital improvement projects. Before design can begin, existing conditions need to be re-established from databases of unknown quality, or by visiting the site. Connecticut has begun work on an authoritative inventory that will be updated from new construction projects. The BIM for infrastructure effort will also capture how old assets are decommissioned. This will allow the department to understand the entire life-cycle costs of specific assets from cradle to cradle. Connecticut's objective is to manage data as an asset, and make it accessible throughout the agency.

Figure 1. Graphic. Connecticut DOT BIM noteworthy practice summary.

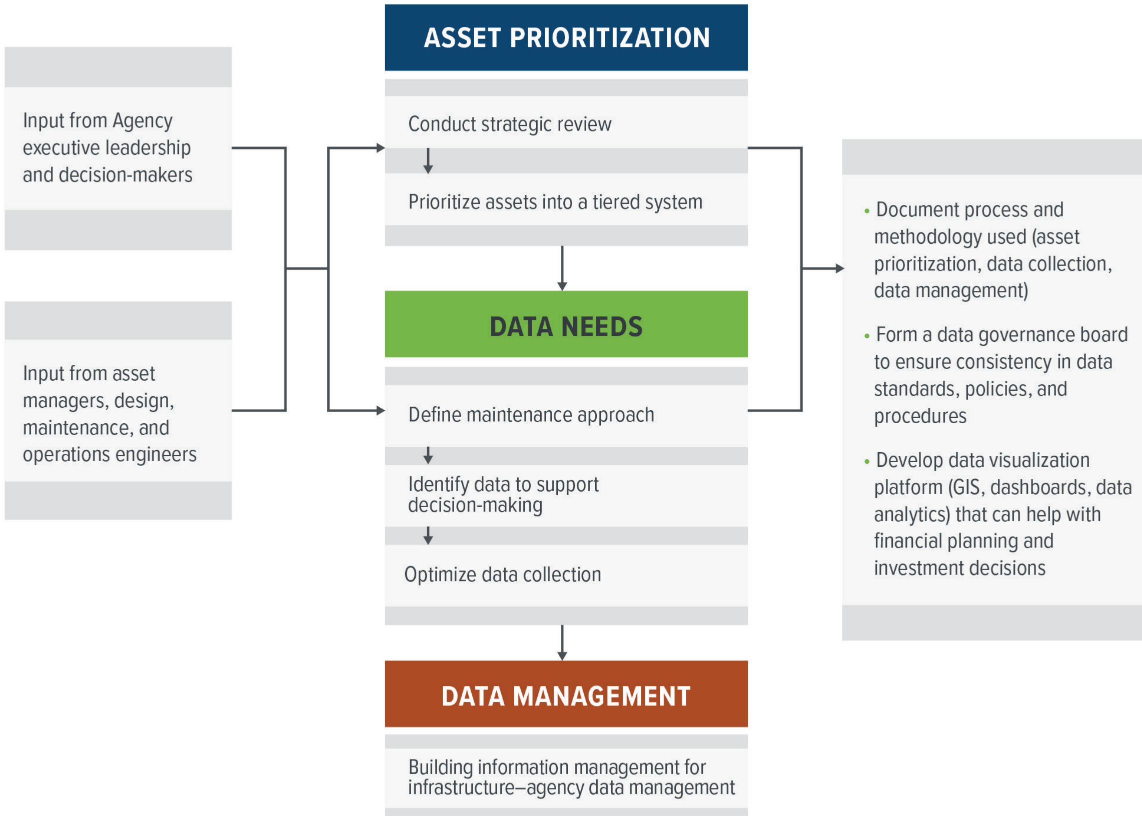


Figure 2. Graphic. Framework for selecting assets and data.

TARGET AUDIENCE

Implementing TAM makes use of collaboration from business units across the agency, including maintenance, engineering, planning, and IT. This handbook is intended to be used by managers who are involved in maintaining and replacing ancillary assets or who are involved in managing the IT systems used to support the decision-making process. While topics such as management strategy and IT architecture are discussed, these topics are presented to inform and provide context to transportation managers. Readers who wish for more detail on subjects such as performance-based management, risk management, or IT architecture are encouraged to review the *References* section for additional resources in these areas.

CHAPTER 2. EFFECTIVE MANAGEMENT OF ANCILLARY ASSETS

USING DATA TO DRIVE DECISIONS

Transportation agencies are tasked with providing a transportation system that moves people, goods, and services safely and efficiently. Although most of the available funding for preserving the systems is spent on highways and bridges, agency personnel are responsible for keeping many other ancillary assets operational, including signs and signals, guardrail (or guiderail), culverts, lighting, pavement markings, and retaining walls. Traditionally, funding has been inadequate to address the maintenance needs of these assets. In response, many agencies allocate their available funding to address the most urgent demands, even if that means postponing scheduled preventive maintenance activities that preserve asset conditions.

As agencies are adopting TAM principles, they are discovering that there are more effective ways to manage their assets using data-driven decisions. Since most agencies have inventory and condition information on their pavements and bridges, it has been relatively easy to transition to a performance-based decision process for those assets. With less information available about the ancillary assets that are maintained, the transition to using data-driven decisions for managing other assets has been a little slower.

Even so, some agencies have made progress using data for managing some of their ancillary assets. For instance, many agencies have implemented MQA programs that help maintenance personnel identify and prioritize maintenance needs. Several agencies have taken it a step further by incorporating one or more classes of ancillary assets into their agency's TAMP. Figure 3 shows some of the assets included in Minnesota DOT's initial TAMP.

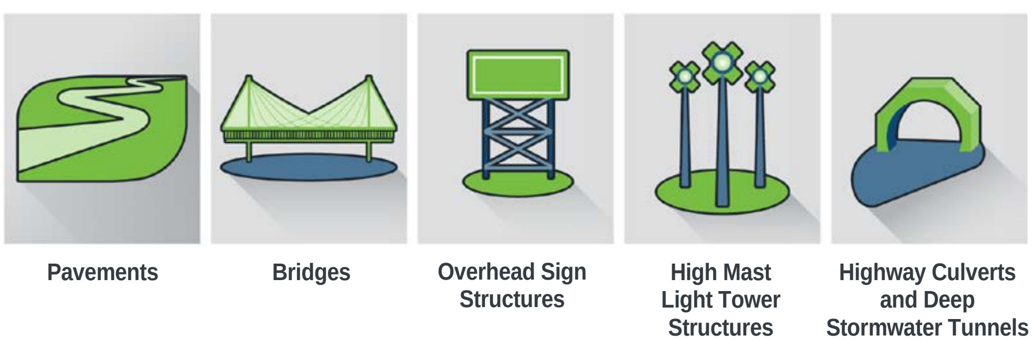
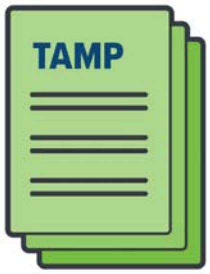


Figure 3. Graphic. Assets included in the initial Minnesota DOT TAMP.



TYPICAL TAMP CONTENT

- Summary of asset inventory
- Summary of asset conditions
- Objectives, measures, and targets
- Comparison of conditions to targets
- Life-cycle planning
- Risk-management practices
- Financial plan
- Investment strategies

The development of a TAMP is relatively new to transportation agencies in the United States, but TAMPs to establish funding needs and set multiyear investment plans are common in government agencies around the world. TAMPs are now required by Federal statute (23 USC 119(e)) and regulation (23 CFR part 515) to document the 10-year investment strategy that State transportation agencies will use to reduce risks and preserve or improve the condition of the pavements and bridges on the National Highway System. The minimum content required to be in Federally-compliant TAMPs is shown in the call-out box at left (23 USC 119(e)(4)). However, agencies may choose to include additional information in their TAMPs.

The inclusion of ancillary assets in a TAMP helps raise awareness for maintenance funding needs and has the potential to positively influence the amount of funding allocated to address these needs. For those reasons, maintenance personnel have shown interest in building more complete inventories for ancillary assets and adopting procedures to evaluate their performance on a regular basis. Since resources are typically too constrained to collect inventory and condition information on all assets at once, a process is needed to help agency personnel prioritize the order in which asset data is collected.

AN INTRODUCTION TO PERFORMANCE-BASED MANAGEMENT

The performance-based decisions that are the foundation to TAM use agency goals and objectives to drive the allocation of resources. Performance information is collected regularly to monitor whether progress is being made toward agency goals and to communicate additional needs to key stakeholders and the public. The availability of data to support investment decisions also helps improve the transparency of budgeting decisions and enables agencies to demonstrate that they are using public funds wisely. There are several benefits to the use of performance-based decisions for managing ancillary assets, as listed below:

- Available funding is used to achieve agency goals and objectives.
- Resources are aligned with agency priorities.
- Agencies have the information needed to support funding needs.
- Planning and programming decisions are transparent.
- Agency accountability is improved.

The Government Accountability Office (GAO) introduced four key components to implementing performance-based management to manage operational activities, as shown in figure 4 (GAO, 1996).

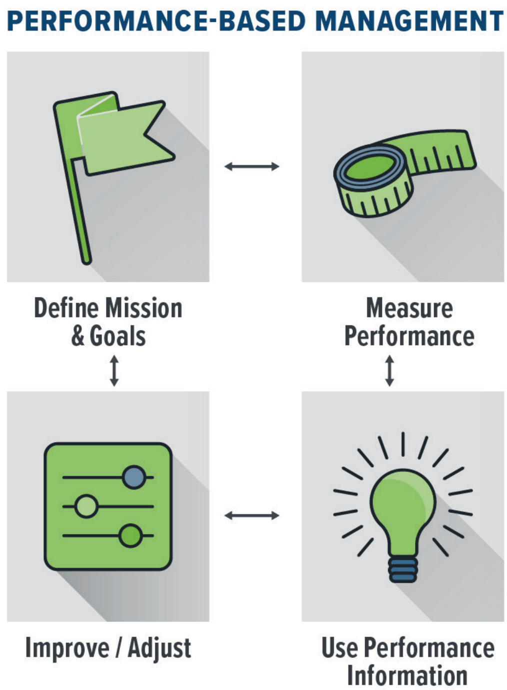


Figure 4. Graphic. Key components to managing assets with performance data (adapted from GAO 1996).

First, the agency should define its goals and objectives so resources can be aligned with agency priorities.

Secondly, the agency should develop a set of performance measures at each organizational level that aligns with the overall goals. For example, an agency goal to maintain 80 percent of the network in good condition might necessitate performance measures for assessing the condition of each asset the agency maintains. The selected performance measures should drive decisions and be practical to collect.

The third component to performance-based management is to use the performance data to make decisions at all levels. Some maintenance personnel use MQA data to identify and prioritize maintenance needs for ancillary assets. Only a few agencies are currently using this performance data to determine the level of funding allocated to maintenance. As agencies become more confident in their use of performance-based management for ancillary assets, the use of the data at the policy level, where funding allocation decisions are usually made, is expected to increase.

The last component involves institutionalizing performance-based management into the organization’s daily operations. This involves balancing responsibilities with accountability and evaluating the process regularly to ensure measures are driving the right decisions (GAO 1996).

EVALUATING THE NEED TO COLLECT ADDITIONAL DATA

The decision to collect additional information on one or more ancillary assets is a strategic decision that each agency makes independently. For that reason, the methodology begins with a strategic review of agency needs (as summarized previously in figure 2).

While most agencies recognize the advantages to having complete and accurate inventory and condition information on their assets, the resources to keep the information current ought to be available, and existing business processes and software tools are necessary to support the analysis and reporting of the information.

As shown in figure 5, this strategic assessment is usually driven by risks that the agency is trying to manage, organizational or technical changes that make new processes possible, or gaps between existing and desired management practices. The agency's strategic review should consider agency policies, budgets, resources, and performance, as well as any legislated mandates and available technology, when deciding to expand its data collection efforts to include ancillary assets. Each of the key drivers in the process is explained further in the following subsections.

Figure 5. Graphic. Factors influencing the strategic review process.

The Types of Changes That Drive the Decision to Collect Ancillary Asset Data

There are many factors that could trigger a change in an agency's requirements, priorities, or procedures that might drive the need to collect additional ancillary asset data. For example, an agency could decide to:

- Make performance-based investment decisions for assets other than pavements and bridges.
- Invest in new technology, such as LiDAR, to see what information can be obtained from it.
- Better integrate information across business units, leading to a review of future data needs.
- Better understand the cost of constructing, maintaining, preserving, rehabilitating, and replacing assets other than pavements and bridges.
- Adopt changes to avoid continued damage due to recurring events such as slope failures or flooding.
- Develop a process that better responds to requests for funds to expand data collection efforts from various business units within the agency.

Any of these types of changes should prompt the agency to evaluate its data needs using the process described in chapter 2. Figure 6 provides a summary of how a strategic review led Virginia DOT to replace its maintenance management system (MMS) to improve consistency and quality of management practices across Districts.

The Types of Risks That Drive the Decision to Collect Ancillary Asset Data

Risks are the potential impact of uncertainty on agency objectives. Risks can be negative, presenting threats, or positive, presenting opportunities. A risk assessment could lead agencies to question whether they have sufficient data to manage their risks adequately. For instance, an agency that is anticipating an increased potential for devastating destruction to the transportation system due to unexpected weather or seismic events might make a strategic decision to collect the data needed to better assess or manage that risk. Risks could also lead an agency to invest in new technologies or approaches that allow it to make better use of its resources. The following list includes some questions that an agency could use to evaluate whether risks might be reduced by having additional data on ancillary assets available:

- Does the agency have areas that have been damaged several times over the last few years due to weather or other events?
- Could a program to clean and/or repair culverts lead to less damage due to flooding?
- Can the agency quantify the impacts that maintenance cuts have on safety, mobility, and asset conditions?
- Does the agency have a good understanding of the percentage of ITS assets that have exceeded the expected manufacturers' life estimate by more than 50 percent?
- Are there any legislated deadlines that the agency is at risk of missing?
- Are agency software systems so outdated that they have become difficult to maintain?

VDOT Virginia Department of Transportation

Through a strategic review of its IT systems, the Virginia DOT recognized that its current maintenance management system (MMS) required updating to better take advantage of new technology. The agency needed a modern MMS that supported mobile devices for field personnel while improving the management of asset data to drive maintenance budgets, work orders, work reporting, and performance management. During the review, the agency recognized several additional issues:

- The MMS was not being used consistently by all Districts.
- The asset inventory data was not well connected to budget and work-planning activities.
- There was no centralized guidance on asset data collection practices.
- District resources available to support MMS were insufficient.
- Districts made their own decisions regarding data collection priorities in the absence of data collection guidance and inadequate resources.

Based on these findings, Virginia DOT developed an RFP for a new MMS and established an oversight committee to determine which assets and data elements would be collected by all Districts and how the data would be collected consistently.

To implement the new MMS, VDOT has focused on planning out the data sets for each asset to eliminate redundant data and make sure asset data adequately supports the agency's management needs. This effort is supported by a cross-disciplined team that is enabling VDOT to both design a more effective MMS and put in place improved data management practices.

Figure 6. Graphic. Summary of Virginia DOT strategic review noteworthy practice.

The Types of Gaps That Drive the Decision to Collect Ancillary Asset Data

A strategic review of an agency's business processes and tools to support asset management might identify several gaps between desired and actual performance. Strategies to address the gaps might include several different steps, including additional data collection and management. For instance, a strategic review might indicate that business units within the transportation agency are each individually procuring data collection services and maintaining nonintegrated data sets to support their ongoing responsibilities.

Organizationally, this approach may not be desirable from a data and systems governance perspective. Since the independent systems may not easily "talk" to one another, there is a potential for duplicative data being collected in several business units, and the data collected by one group may not satisfy the needs of another group. NCHRP Report 814, *Transportation Agency Self-Assessment of Data to Support Business Needs: Final Research Report* (NCHRP 2015a), tackled this challenge and provided a checklist, summarized in figure 7, to use when conducting a strategic review of existing data gaps.

AGENCY DATA CHECKLIST

- Develop strategic plan—policies, interdepartmental coordination, data governance
- Develop a goal or vision: *"One Version of Truth"*
- Determine business system improvements
- Determine authoritative division and agency data
- Prioritize assets to inventory
- Determine how data will be integrated into existing business systems
- Determine how business systems, processes, and procedures need to evolve to consume the new data
- Determine how collections take place—field apps, integrated MMS, complete collection
- Determine how data will be used for TAMP, maintenance work plans, budgets, STIP, and other agency plans
- Collaborate and think agency wide

Figure 7. Graphic. Agency data checklist (NCHRP 2015a).

Examples of the types of gaps that might drive an agency to consider collecting additional data on ancillary assets include those listed below:

- The agency may identify gaps in its ability to adequately estimate future maintenance needs for maintenance-related assets.
- Policy or safety issues related to the use of certain products or materials may drive the need to collect data to identify the extent to which replacements will have to be made. In recent years, these types of issues drove several State highway agencies to begin collecting information on the manufacturer of in-place guardrail end treatments.
- The impact of potential changes in State or Federal standards may not be well understood because of the lack of reliable data.
- Existing software tools might not have the features needed to manage ancillary assets using a performance-based approach.
- Data may not be integrated in a way that supports BIM for infrastructure.

CHAPTER 3. SELECTING ASSETS FOR INCLUSION IN ASSET MANAGEMENT PROGRAMS

INTRODUCTION

Given unlimited resources, transportation agencies would have full inventories of all their assets with frequent and thorough condition assessments. However, facing the realities of limited resources and budget constraints, agencies are forced to make difficult decisions regarding how extensively available resources are dedicated to collecting, managing, and using asset information versus delivering work that preserves and improves asset conditions and system performance. Agencies looking to expand their asset management programs to include additional information need a means of determining the benefits and costs associated with system development, data collection, and data management. This chapter describes the activities associated with the second step in the methodology introduced in chapter 1, Prioritizing Assets.

Figure 8 shows processes, products, and keys to success related to the activities involved in developing a prioritized asset list. These products and process steps are generic to agency type, organizational structure, or assets under consideration. Each agency should tailor these steps to their specific needs and determine the best means of executing each step.

Process

Prioritization is essential to ensure the effective and efficient use of limited resources. This chapter introduces a seven-step process framework that leverages coordination between business units that have a need for asset data or have a role in collecting or managing asset data. This framework can be modified to fit the needs of each agency.

Prioritizing asset classes for inclusion in an agency's asset management program relies on an understanding of the agency's IT policies, architecture, and strategies. Asset management systems, where asset data are typically stored and analyzed, are IT systems that need to serve the full agency. The agency's IT strategy for managing and sharing data is a significant factor in determining the level of effort and cost needed to implement asset management systems that support the agency's decision-making processes. If the agency has not documented its IT strategy for asset data, the prioritization process offers a good opportunity to do so. Chapter 5 provides an overview of what should be considered when developing an IT strategy for managing asset data using the BIM for infrastructure approach.

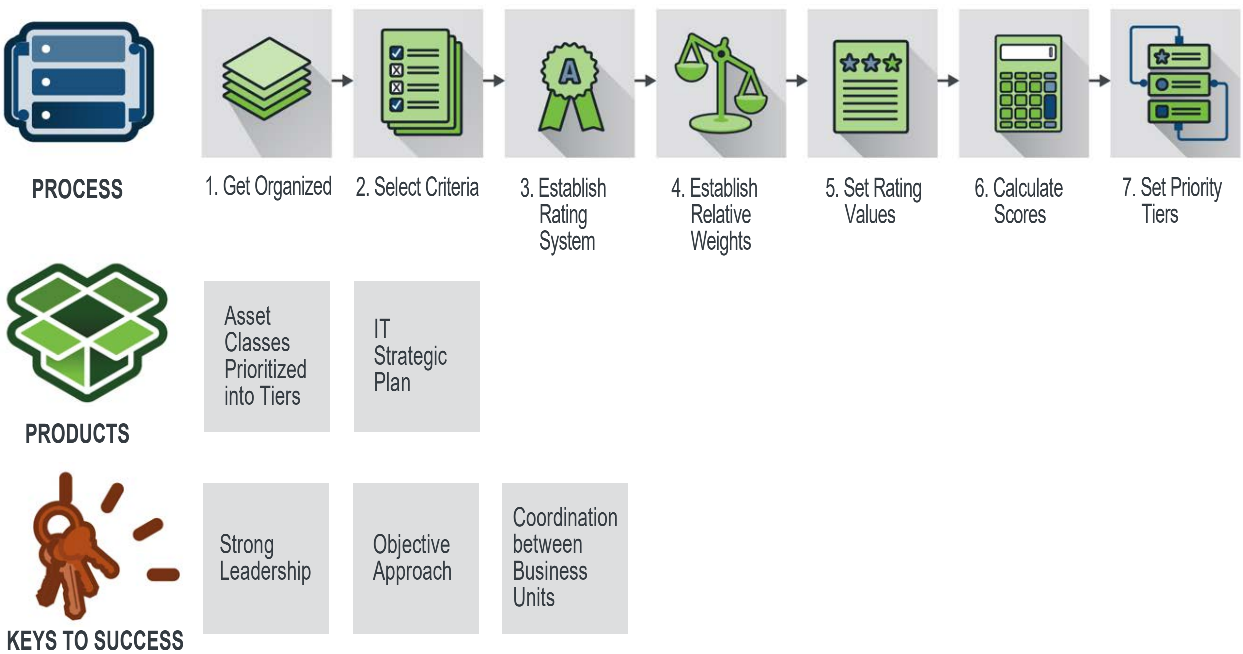


Figure 8. Graphic. Products, process, and keys to success for prioritizing asset classes.

Products

The primary product of an asset-prioritization effort is a prioritized list of asset classes for inclusion in the agency's TAM program, with the asset classes grouped into tiers. A secondary product may be a TAM-IT strategy to support implementation of the prioritized list. Together, the list of prioritized asset classes and the documented IT strategy can support justification of investments in expanding asset management systems and help align efforts to improve data collection and data sharing practices.

Keys to Success

It is important to understand how data can be utilized by different business units to achieve the agency's mission and goals. For example, safety, maintenance, and design units may have a need for information about the agency's guardrail. This approach requires a team to be assembled to review the agency's relevant goals, policies, and practices related to performance management and asset management.

STEP 1: GET ORGANIZED

Leadership is critical to the success of any coordinated effort. There are two distinct leadership roles for this effort: Champion and Project Manager*.* At public agencies, these roles are rarely formalized, but they are common to nearly all successful efforts related to expanding asset management programs to include ancillary assets. The Champion should be an individual with the authority to ensure the cooperation of all needed business units. The Champion's role is to communicate the vision to the full team and ensure that the effort is focused on maximizing value for the entire agency. The Champion will either have the authority to approve the final recommendations or be responsible for attaining approval from the appropriate authority.

The Project Manager is responsible for planning the effort and managing daily activities. Planning can include defining specific tasks and assigning them to team members with deadlines. Effective project managers ensure the team is participating as needed and the work products are developed on time. For efforts involving only agency staff, the Project Manager's role is typically informal. If the effort includes outside support, such as a consulting firm or IT vendor, the Project Manager's role is likely to be more formal and include budget responsibilities.

Once project leadership has been established, it is important to identify all the stakeholders who might have an interest in using, managing, or collecting information about ancillary assets. An example of potential stakeholders is shown in figure 9.

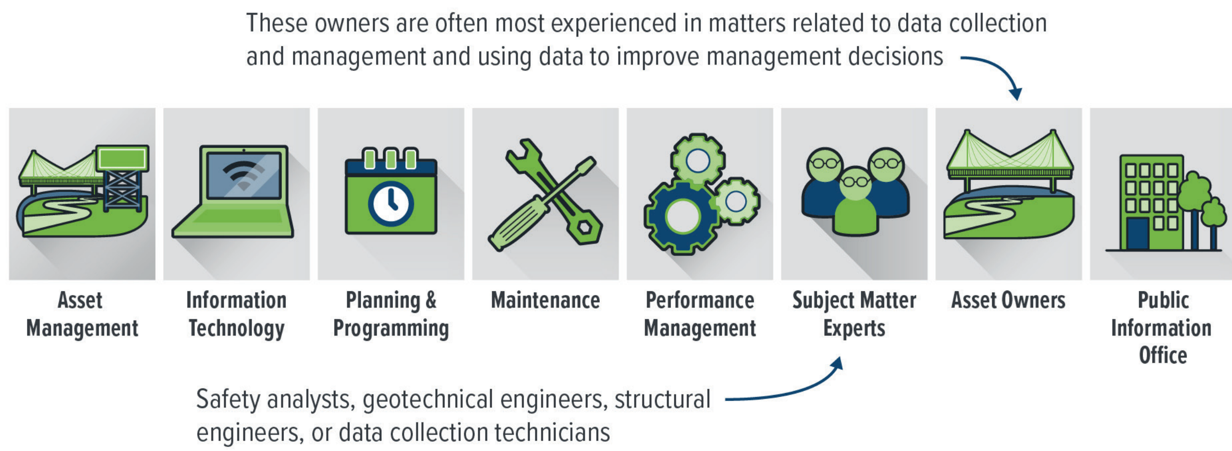


Figure 9. Graphic. Typical business units contributing to asset priorities.

Project leadership should contact these potential stakeholders to determine need and interest in participating in the effort. This outreach will establish an initial range of assets to be included in the prioritization effort. For example, the effort may be limited to deployed or constructed highway infrastructure, or it may include similar assets in different modes, or assets such as fleet equipment that are used to service the infrastructure. This outreach should identify:

- The known needs of each business unit for asset data.
- A general understanding of each unit's current asset data.
- An initial assessment of each unit's current analysis and reporting capabilities.

Based on the results of the initial outreach, a project team that represents all business areas with either a need for information on the assets included in the prioritization effort or a role in collecting or managing the necessary data should be assembled. Figure 10 provides a list of business areas involved in implementing Minnesota DOT's asset management system. By involving a wide array of stakeholders in the early stages of planning its asset management program, Minnesota DOT was able to include multiple assets in its initial TAMP and develop a long-term strategy for adding additional assets.

Individuals selected to participate in the asset prioritization effort should include the people expected to be responsible for developing and overseeing data collection and data management policies, procedures, and contracts. This helps ensure later efforts are coordinated, efficient, and in line with the overall asset management vision.

The team may also benefit from including individuals who have experience with similar assets, or who have participated in similar efforts. For example, if the prioritization effort is focusing on highway assets, but the agency already has asset data for aviation or transit assets, individuals who were involved in the earlier efforts could provide valuable experience to the team.

DEPARTMENT OF TRANSPORTATION

When Minnesota DOT began to plan for its asset management system, the agency created a new position to lead the effort. However, the full effort was not left to one individual. To collect and document information on the benefits and costs of collecting, managing, and using asset data, the project lead reached out to multiple internal and external units, including:

- Asset Management Steering Committee
- Asset Management Project Office (AMPO)
- Specialty/expert offices (e.g., Safety, Maintenance, and Operations)
- District Maintenance and Operations Managers
- Minnesota IT Services (MnIT) project management and contracting personnel
- MnDOT Administrative personnel (materials management, financial)
- MnDOT TIM office
- Vendor personnel*

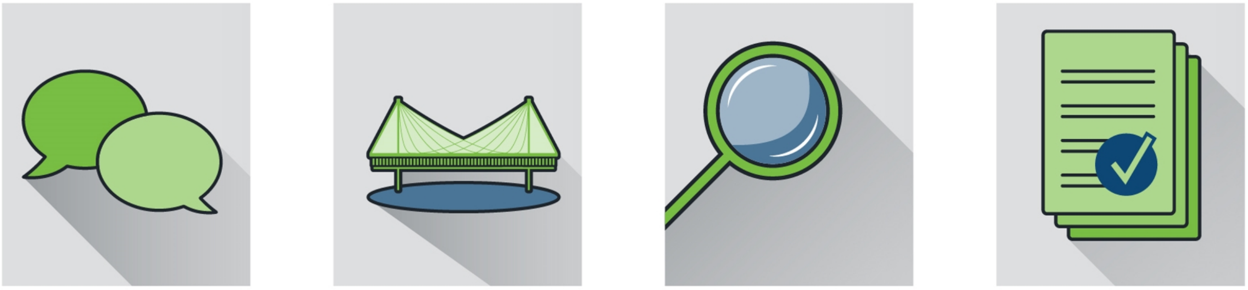
*MnDOT had already selected an IT Vendor.

Figure 10. Graphic. Minnesota DOT's asset management system implementation team.

Several factors have allowed Ohio DOT to advance in its asset management implementation and data integration efforts. Primary among these is the establishment of their Asset Management Leadership Team, shown in figure 11. Within the Asset Management Leadership Team is a TAM Audit Group that is responsible for ensuring that asset management data is well defined, consistent with agency needs, and able to be efficiently collected and managed.

The final aspect of organizing the effort is to define the list of asset classes to be considered in the prioritization process. This is more involved than simply providing asset class names. In addition to names, the list should provide a definition for each asset class, making it clear how each class differs from the others. A common example of asset classes that make use of specific definitions to be consistently identified are culvert pipes and storm sewer systems. Typically, culverts are single pipes that are open at both ends. However, it is not uncommon for multiple culverts to connect or for culverts to be fed from surface drains. Several connected culverts, which are fed by surface drains, may be considered a storm sewer system. Agencies should strive to define each asset class as specifically as possible. Table 1 provides a list of common ancillary asset classes that State DOTs might consider including in their asset management program.

ASSET MANAGEMENT LEADERSHIP TEAM



Communications Group

- Comprised of Central Office and District personnel
- Communicates TAMP messages throughout all levels of ODOT and externally
- Designs and implements communication plans for ODOT's strategic direction and measures its effectiveness

Infrastructure Group

- Comprised of Central Office and District personnel
- Provides oversight during the development of the Work Plan
- Ensures business needs of Planning, Operations, Engineering, Construction, and other functions are represented in all aspects of TAM activities

TAM Audit Group

- Comprised of Central Office and District personnel
- Oversees all asset data collection requirements
- Ensures data governance and collection standards are in place for any asset data collected by the Department

Data Governance Group

- Comprised of Central Office and District personnel
- Sets agency standards
- Develops data governance and data collection standards for all asset data collected by the Department

Figure 11. Graphic. Ohio DOT Asset Management Leadership Team groups.

Table 1. Typical highway asset classes (adapted from NHI 2017).

FUNCTIONAL AREA	ASSET CLASS
Structures (not Bridges or otherwise in the National Bridge Inventory)	• Drainage Structures • Overhead Sign and Signal • Retaining Walls (Earth Retaining Structures) • Noise Barriers • Sight Barrier • High-Mast Light Poles
Traffic Control and Management—Active Devices	• Signals • ITS Equipment • Network Backbone
Traffic Control and Management—Passive Control Devices	• Signs • Guardrail • Guardrail End Treatments • Impact Attenuator • Other Barrier Systems

FUNCTIONAL AREA	ASSET CLASS
Drainage Systems and Environmental Mitigation Features	• Drain Inlets and Outlets • Culverts (<20 ft. total span)/Pipes • Ditches • Stormwater Retention Systems • Curb and Gutter • Erosion Control • Other Drains (e.g. Underdrain and edge drain)
Other Safety Features	• Lighting • Pavement Markings • Rockfall
Roadside Features	• Sidewalks • Curbs • Fence • Turf • Brush Control • Roadside Hazard • Landscaping • Access Ramps • Bike Paths
Other Facilities and Other Items	• Rest areas • Weigh stations • Parking lots • Buildings • Fleet • Roadside graffiti • Roadside litter

STEP 2: SELECT CRITERIA

An objective prioritization process requires the establishment of common criteria for comparing each asset under consideration. By selecting criteria, the team is identifying what matters to them when determining asset class priority, and what does not. Criteria used to prioritize asset classes should reflect the benefit or cost of including each asset class in the asset management program. Each criterion has three components to maximize the objectivity of the process:

- The attribute, benefit, cost, or risk being considered to differentiate between asset classes.
- A means of rating each asset regarding the criterion.
- A weight assigned to signify the relative importance of each criterion in relation to the others.

While each agency will need to select criteria to meet its specific needs, there are common categories that should be considered: importance, external influence, need to respond impact on the agency's mission, effort and cost to implement, risk, and organizational readiness. Following are descriptions and details on the types of information that can be used to define and rate each of the criteria.

Importance

How important is the asset to the agency and its mission? This can also be described as the priority the agency places on the asset or the urgency normally placed on keeping the asset in service. Importance can be assessed in many ways. Possibly, the most common way is the cost to replace existing assets with assets meeting current standards. This can be very difficult when no asset inventory is in place. For assets without existing inventories, it may be easiest to assess the amount spent on annual maintenance, repair, and replacement efforts.

It is recommended that this effort consider capital expansion trends to consider the total value or annual maintenance needs at some point in the future. ITS assets can be used as an example of the importance of looking forward. In most locations, the total value of deployed ITS assets in the year 1990 was relatively small. By the year 2000 the value of deployed assets had grown significantly, but the annual maintenance and replacement costs were still relatively small because the assets were new. By 2010, the ITS maintenance and repair costs became a significant expense for many State DOTs.

External Influence

Transportation agencies do not operate independent of external influences. Some external groups, typically government entities, can direct agencies to act through statute, regulation, or mandate. For example, Federal statute requires that States maintain inventories for public bridges (23 USC 114). States or localities may have similar mandates for other assets. New York State DOT, for instance, operates under a general permit for the State Pollutant Discharge Elimination System,[1] which requires the DOT to inventory and periodically inspect all outfalls of stormwater from its highways.

Other regulations may not directly require an inventory but it may be challenging to meet the requirements without one. The Americans with Disabilities Act (ADA) (42 U.S.C. § 12101, et seq.) does not require facility owners to inventory assets that provide access to the transportation system. However, maintaining pedestrian facilities that comply with the ADA requirements without an inventory can be extremely difficult for a large agency such as a State DOT. In some cases, failure to maintain these assets in compliance with regulations has led to court or administrative findings, which led agencies to obtain inventory and condition data for related assets.

[1] New York State Article 17 Title 8, Environmental Conservation Law Implementing Regulations - 6NYCRR Part 750.

Need to Respond

Government transportation agencies exist to serve the public. While agencies may not be under any specific mandate to respond to the public concerns, it is generally expected that these agencies should be responsive to significant concerns raised by stakeholder groups or the general public. The ability to quickly and accurately answer questions from the public or other stakeholder groups goes a long way toward establishing a positive agency reputation. The callout box presents examples of the type of the information that may be requested from the maintenance units and how BIM can help in addressing them.

Impact on the Agency's Mission

As described in Chapter 2, a performance-based management system supports delivery of the agency's mission by establishing and tracking measurable goals, objectives, and targets. Any asset prioritization effort should be directly tied to the agency's mission and any existing goals and objectives. Typically, these will include some aspects of efficiency, safety, environmental stewardship, and economic growth.

While it may be difficult to directly tie asset conditions to broad goals, such as safety improvement, it is very likely that a connection can be made to initiatives or programs that have been established or identified. For example, the agency may have identified updating nonstandard guardrail systems as a means of improving system-wide safety. In many cases, measurable goals or targets have been established and can be used to evaluate the criteria.

4 O'CLOCK FRIDAY AFTERNOON CALL TO MAINTENANCE

At any given time, agency executives, legislators, and the public may wish to know any number of maintenance metrics, such as number of poor signs replaced, preservation projects completed, or winter snow and ice financial information. Follow-up questions might include the request to display this information on a map, with the ability to query by region, district, state route, city, or legislative district. Generally, to answer these types of questions the maintenance office would need to review different databases, such as financial, maintenance, planning, functional classification, and geospatial.

Building Information Management, or BIM, is a philosophy that promotes data as an asset that is managed and shared. Agencies that organize and manage their data as an asset will be able to answer these and many other 4 o'clock Friday afternoon calls.

Effort and Cost to Implement

Many factors contribute to the cost and effort of implementing an asset inventory and inspection program. This evaluation should consider both initial and recurring resource needs. Including an asset class in an asset management program requires more than developing an inventory database and making the data available to field staff. Many factors need to be evaluated, including data standards, data collection, quality control, quality assurance, staffing levels, and contract costs. Often when agencies are looking to implement agency-wide or "enterprise" asset management systems, there have already been efforts made by individual business units. These initial efforts can be leveraged to reduce initial resource needs and maximize the likelihood that the asset data is kept current and is used to improve business practices and performance. Table 2 lists the types of criteria suggested for evaluating costs and level of effort to implement.

Table 2. Criteria for evaluating costs and level of effort.

FACTOR	DESCRIPTION	POTENTIAL CRITERIA
Existing Data	Having even partial inventories in place can greatly reduce the resource needs to implement a new inventory system. However, if data has been collected by different means, to different standards, or is out of date, considerable effort may be needed to make the data suitable for the identified purposes.	• Full inventory of the asset class established • Condition assessment data to support business needs established • Data quality is adequate to support business needs
Performance Management	Since the purpose of the asset management system is to support a performance-based process for managing asset conditions, any prior efforts to develop performance programs for an asset can reduce initial costs and help ensure continued use.	• Performance goals have been established • Performance measures have been identified • Performance targets have been set
Analysis	Asset management analysis uses data on current and past conditions, and investments to predict the impact of future investments. Considerable research may be needed to model how asset conditions deteriorate with time and usage, and how different treatment applications improve conditions. While performance will vary based on environmental, material, and usage factors, agencies can often take advantage of work done by others. Pavement and bridge management systems are commonly implemented with "typical" performance models, until the agency can develop custom models.	• Treatment strategies have been defined • Treatment costs are known • Treatment decision trees have been developed • Deterioration rates are understood • Treatment benefits (improvement to conditions) are understood • Standard analysis tools or processes have or can be obtained
Data Collection	While the initial cost of asset management systems can be significant, the data collection is the largest cost in the life of any system. Agencies should seek every possible efficiency while collecting data of sufficient quality for their needs.	• Cost of data collection • Data collection can be combined with other current data collection efforts • Data collection can be combined with other new data collection efforts • Data collection standards exist • The complexity, difficulty, of data collection • The data collection cycle

Risk

Risk plays an important role in the prioritization process. Agencies should consider the degree to which asset data helps the agency address gaps in the agency's asset management program, mitigate threats, or take advantage of opportunities in weighing the priority of each asset class. The following are examples of threats and opportunities that can be addressed with asset data:

- Inventory data can allow rapid access to information to determine which assets comply with new safety or structural standards.
- Knowledge of assets susceptible to flooding can improve the efficiency of emergency response plans.

If the agency has a robust risk-management program, then risk-based criteria can be developed by reviewing the agency's risk register. If the agency does not have an ongoing risk-management process, the asset prioritization team can identify criteria by asking the following:

- Can the data be used to reduce the likelihood or consequences of a known threat?
- Can the data be used to take advantage of future opportunities?

Agencies wishing to learn more about risk management at transportation agencies may wish to read the *Guide for Enterprise Risk Management* published by the American Association of State Highway and Transportation Officials (AASHTO).

Organizational Readiness

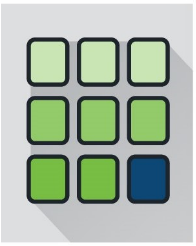
Organizational readiness refers to the organization's ability to take advantage of the new or expanded asset management information once it is in place. Agencies can invest millions of dollars and thousands of hours of staff time developing IT systems, researching performance models, and collecting data, but these investments are of little benefit unless the data and analysis are used to improve business decisions. Staff should be available to keep the data current and run analyses. Data should be accessible to those who need it. Management processes need to be in place to use the data and information to improve performance. Figure 12 presents an example checklist that can be used to assess organizational readiness. Figure 13 summarizes the various prioritization categories and criteria used by the Minnesota DOT during the development of the Minnesota State Highway Investment Plan (MnSHIP).

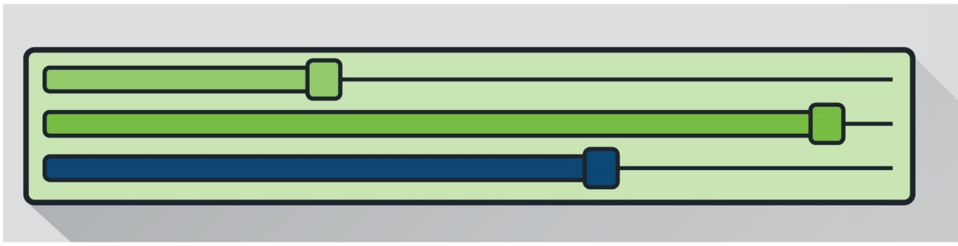
ASSET CLASS	No, and there are no current efforts to assign, implement, or develop.	No, but there are current efforts to assign, implement, or develop.	Yes
1. Has an asset "owner" unit been identified?	1	2	3
2. Has an asset "owner" lead been identified?	1	2	3
3. Do staff have adequate knowledge and expertise?	1	2	3
4. Are decision-making processes in place that can take advantage of the new data or information?	1	2	3
5. Are necessary resources available to populate, manage, and run the system?	1	2	3
		Total Score	

Figure 12. Graphic. Organizational readiness checklist.

NOTEWORTHY PRACTICE: MINNESOTA DOT PRIORITIZATION CRITERIA

Minnesota DOT developed a spreadsheet with columns for each criterion and rows for each asset. The spreadsheet was distributed to stakeholders across business units. Stakeholder input was then compiled and analyzed by the project lead. The resulting prioritized list of assets was vetted by the Asset Management Steering Committee before being adopted.





Category	Criteria
Asset Information	• Asset inventory size (level of impact) • Statewide or metro-only impact • Asset complexity—interactions with other databases • Completeness of current inventory • Quality of current data
Existing Management System, Replacement Project	• Current management system name • Management system health, functionality • Management system maintenance costs • Relative [selected vendor] maintenance costs • Relative level of vendor resources required • Relative level of MnIT resources required • Relative level of asset management team resources required
Business Readiness	• Breadth of organization impacted, involved, or benefited • Staff needs to develop or remediate data • System measures and targets • Operations measures and targets • Effort to deliver resource demand model • Stakeholder level of interest • Stakeholder availability • Asset in TAMP, Minnesota State Highway Improvement Program (MnSHIP), Products and Services

Figure 13. Graphic. Minnesota DOT asset prioritization criteria.

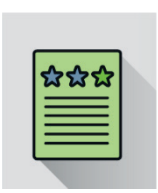
STEP 3: ESTABLISH RATING SYSTEM

Once criteria have been selected, it is important to establish a means of rating each criterion. The simplest means of rating objectively is to select a numeric scale. It is recommended that scales of either 1 to 5 or 1 to 10 are used and that the same scale is used for all criteria. However, some criteria cannot be rated objectively in this way. In addition to the numerical scale, some criteria may be rated using a yes/no option. Other criteria may be more subjective in nature.

Examples of how quantitative ratings can be established for criteria is provided in table 3, which is adapted from NHI Course 134112 *Enhanced Maintenance Management Systems* (NHI 2017). This example uses a rating scale of 1 to 5. Using a larger scale, such as 1 to 10, allows raters to distinguish smaller differences between conditions or situations. Scales larger than 1 to 10 are not recommended as these can become confusing to raters and may not provide sufficient differences between condition rating values.

STEP 4: ESTABLISH RELATIVE WEIGHTS

Weighting criteria allow agencies to consider the relative importance of different criteria. For example, an agency may not feel that the difficulty of collecting data is as important as the importance of the data in meeting agency goals. Care should be taken in establishing weights, and agencies may want to use an iterative process to adjust weights after the development of a prioritized list of assets. Since this method recommends transforming the calculated priorities into broader tiers, the weighting method can be relatively simple. Weighting can only be used for criteria that have been assessed using a common numeric scale. Criteria evaluated based on yes/no or subjective means are not appropriate for weighting. If agencies wish to learn more about establishing relative weights for selection criteria, NCHRP Report 806, *Guide to Cross-Asset Resource Allocation and the Impact on Transportation System Performance*, provides information on several methods for establishing weights.



STEP 5: SET RATING VALUES

Once the evaluation criteria have been selected and the ratings and weights have been established, the prioritization team can begin the process of rating each asset according to each criterion. It is recommended that the rating values are developed through one or more workshops during which raters work together to develop single priority ratings for each asset class.

A workshop approach allows for conversation and for raters to be influenced by each other's knowledge. Workshop facilitation is critical to ensure that all participants have an opportunity to contribute to the process. The travel costs associated with workshops can be mitigated, at least in part, through web meetings and conference calls. Scheduling conflicts can be mitigated by holding several smaller workshops or a series of meetings instead of one large event.

Table 3. Example of rating values (adapted from NHI 2017).

a. Availability of standards for data collection.

LEVEL	RATING
No standards available or planned	1
Standards under development	2
Standards inconsistent among agencies	3
Experimental standards	4
Widely accepted standards	5

b. Relative quantity and dollar value of the asset.

LEVEL	RATING
Not important (< 1%)	1
Somewhat important (1–5%)	2
Moderately important (5–10%)	3
Important (10–20%)	4
Very Important (> 20%)	5

c. Relative importance of the asset to the agency and road users.

LEVEL	RATING
Not important to majority of users	1
Somewhat important	2
Moderately important	3
Important	4
Very important—**Assign a rating of 5 to any high-risk assets**	5

d. Availability of automated data collection tools.

LEVEL	RATING
No automated procedures	1
Automated procedures under development	2
Experimental automated procedures	3
Automated procedures inconsistent among agencies	4
Widely accepted automated procedures	5

e. Frequency of data collection.

LEVEL	RATING
Very infrequently (5–10 years)	1
Infrequently (2–5 years)	2
Annually	3
Frequently (quarterly)	4
Very frequently (monthly)	5

f. Time to implement IT system.

LEVEL	RATING
2 or more years	1
18–24 months	2
12–18 months	3
6–12 months	4
Less than 6 months	5

STEP 6: CALCULATE SCORES

Once all criteria have been rated, the raw priority scores are calculated by multiplying the rating for each criterion by its weight. The final score for the asset class is the sum of all rating-weighting products.

$$\textit{Final score} = (\textit{Rating } 1) \times (\textit{Weight } 1) + (\textit{Rating } 2) \times (\textit{Weight } 2) + \ldots + (\textit{Rating } n) \times (\textit{Weight } n)$$

The final score can be used to develop an initial ranked list of prioritized asset classes. This list can be further refined using yes/no and subjective criteria. Often these criteria are considered in step 7 as assets are grouped into priority tiers.

Ohio DOT held a workshop that identified the threats and opportunities that could be addressed with additional asset data. Threats and opportunities were identified and then ranked based on:

- The relative impact (negative or positive) of the risk or threat occurring.
- The likelihood that asset data could be used to mitigate the risk or take advantage of the opportunity.
- The cost to obtain and manage the data necessary.

The group worked through facilitated exercises to come to a consensus of the benefit and cost of collecting data for each asset class under consideration. Using this benefit and cost data, the workshop participants developed a draft set of priority tiers. Those priorities were vetted through the Asset Management Leadership Team before being adopted as the prioritized tiers shown in table 4. Table 4 also includes the results of the asset prioritization effort conducted by the Nevada DOT. The development of tiers is discussed in the next step, but the differences in the two examples provided in the table reflect differing priorities or different levels of preparedness by each agency.

Table 4. Examples of prioritized tiers developed by Nevada and Ohio DOTs.

TIER LEVEL	NEVADA DOT	OHIO DOT
I	• Pavements • Bridges • ITS assets • Rest areas, buildings and storage facilities	• Pavements • Bridges • Culverts • Barriers/guardrail • Overhead sign structures
II	• Slopes • Guardrails, barriers, impact attenuators • Hydraulic infrastructure • Signs • Sign structures	• Lighting • Retaining walls • Curb ramps • Geotechnical assets
III	• Traffic Signals • Noise barrier walls • Lighting structures • Bike paths and sidewalks • Pavement marking • Weigh stations and pump houses • Retaining walls • Curb and gutter • Embankments • ADA Features • Cattle guards and fences • Landscape features	• Signals • Noise walls • Ground mounted signs • Sidewalks

STEP 7: DEVELOP PRIORITY TIERS

The last step aggregates the information from steps 1–6 to form the agency's prioritized list for expanding the asset classes included in its TAM program. The priority tiers group assets so that plans can be established for collecting, storing, and managing the necessary data.

Determining which assets to include in a specific implementation project depends on many interconnected factors, which makes it challenging to develop an accurate ranked order of all assets. The process can be simplified by using a tiered system, where assets of similar priority are grouped together. Figure 14 illustrates how a ranked order list can be converted to a set of prioritized tiers.

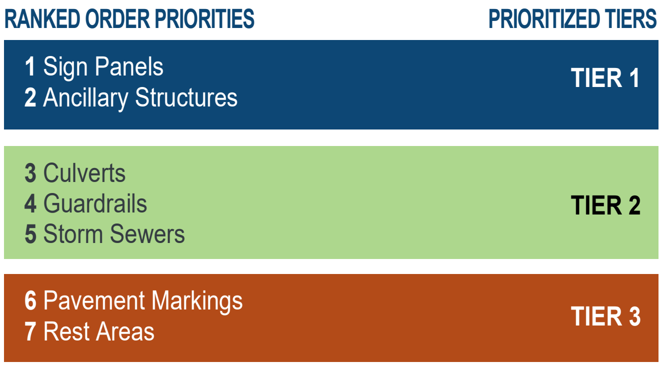


Figure 14. Graphic. Example of ranked order priorities used to create prioritized tiers.

The prioritization process should be kept as objective as possible; however, many of the evaluation criteria are subjective in nature. A tiered methodology recognizes that initial priority scores are just one set of inputs into the final decision of which assets to include in a new or expanding asset management system.

Considerations for data collection, data governance, and available resources will also factor into these decisions. Agencies with a fully developed IT strategy for asset management, particularly one that has established the agency's approach to implementing BIM for infrastructure, will provide much of the information needed to understand the benefits of grouping different asset classes into specific tiers. For example, assets collected by the same means may be combined into a tier, so data collection can be coordinated with data collection service procurement. Similarly, assets may be combined into tiers based on the schedule for adding the data sets to a central data repository.

When an agency has completed the steps in the prioritization process for the first time, the list of priority tiers is not fully informed by the costs associated with data collection and management. These costs may need to be established during the next component of the methodology, as described in chapter 4. If the data collection and management costs result in major changes to the assumptions used in rating the asset criteria, the agency may want to repeat the prioritization process using the updated costs.

SUMMARY

This chapter describes the activities associated with prioritizing the order in which assets may be incorporated into an asset management program. A seven-step process is introduced that can be adapted to the specific needs of each agency. The steps result in a prioritized list of asset classes that are grouped into priority tiers. It is recommended that agencies document their final prioritization process so their tiers can be updated periodically to reflect changes in the inventory status or a better understanding of costs for data collection and management. Chapter 4 presents a process that agencies can follow to determine the data elements needed to manage their ancillary assets and the most cost-effective means of collecting that data.

CHAPTER 4. SELECTING AND COLLECTING DATA

INTRODUCTION

To support TAM, agencies collect, store, manage, and analyze large amounts of data. The data can be used by the agency to identify metrics and define performance measures to verify if a particular maintenance approach is working effectively and how it might be able to be improved. Specific data collection related to asset condition assists with prioritization of repairs, resource allocation, and budgeting. Information shared with the public assists with positive community relations and outreach.

This chapter introduces the activities associated with the second component to the methodology: Data Needs. It provides information that can be used to determine the data needed to support the use of performance-based maintenance decisions for ancillary assets and the best way to collect the data. Figure 15 summarizes the processes, products, and keys to success related to selecting and collecting data for ancillary assets.

Processes

This chapter presents a framework for establishing a performance-based management strategy for ancillary assets, identifying data elements for collection, and selecting the most appropriate data collection techniques. This framework is presented as a set of related processes that can be adapted to each agency's specific needs.

The process for establishing a performance-based management strategy uses the RCM approach. RCM uses a set of risk-based questions to help the agency determine the most effective and efficient approach. Once the management approach is defined, data elements are classified as essential or desired and assessed for priority. Data quality is essential to effectively support decision-making, so data collection approaches are described to help an agency determine the most efficient means of collecting high-quality data.

Products

The framework presented in this chapter will allow agencies to develop three products to support implementation of their TAM program. Following the RCM process, agencies can develop a performance-based management approach for each asset class. Documenting this approach allows the agency to effectively coordinate between functional groups such as maintenance, engineering, and planning. The management approach establishes the types of maintenance activities that the agency will implement to extend asset service lives, as well as the factors that contribute to determining the most effective activity at any point in an asset's life. Using the documented management approach, agencies can identify and document the data needed to manage each asset class. Understanding and documenting the data needs allows agencies to determine the most effective means of data collection for each data element, coordinate between asset classes to avoid redundant data collection activities, and improve overall agency efficiency.

Keys to Success

Successful implementation of the framework presented in this chapter requires an understanding of the intended function, potential failure modes, available maintenance options, and consequences of failure for each asset class. This information is likely not housed in any one functional area or business unit within a single agency. Collecting this information will require coordination between different groups across the agency.

Figure 15. Graphic. Chapter 4 products, processes, and keys to success.

DEFINE A MAINTENANCE APPROACH

DATA NEEDS

X Define maintenance approach

Identify data to support decision-making

Optimize data collection

To know what data is needed to support decision-making, an agency should first understand the decisions that will be made using the data. Before collecting data on a class of assets, the agency should formalize its approach to managing those assets and identify the key decisions that will be made throughout the life of a typical asset in that class. RCM is the process used to determine the most effective maintenance strategy to ensure that a physical asset continues to perform in a manner consistent with design specifications. The RCM process can be used by transportation agencies to plan the type of maintenance approach used for ancillary assets to improve the overall safety and reliability of the asset in a cost-effective manner during the asset's life cycle.

Background

The concept of RCM originated in the airline industry in the 1960s due to the high cost of maintenance activities. RCM took the airline industry from the "the more maintenance the better" mindset to a philosophy that maintenance should be performed when the benefits clearly outweigh the associated risks and costs. In a 1968 study, the maintenance requirements in one example reduced from 200 man-hours per flight hour to 3.3 man-hours per flight hour with the use of RCM (Nowlan and Heap 1978). In addition, when the preventive maintenance was reduced and the time between overhauls of the planes minimized, the aircraft safety and dispatch reliability improved due to reduced maintenance-induced failures.

The highly structured RCM process results in a consensus from stakeholders in the identification of maintenance practices to develop a policy for ease of maintenance and effective operation. The seven basic questions included in the evaluation criteria for the RCM process are as follows (SAE International 2009):

- What is the item supposed to do, and what are its associated performance standards?
- In what ways can it fail to provide the needed or desired functions?
- What are the events that cause each failure?
- What happens when each failure occurs?
- In what way does each failure matter?
- What systematic task can be performed proactively to prevent or diminish to a satisfactory degree the consequences of the failure?
- What needs to be done if a suitable preventive task cannot be found?

RCM integrates the underlying philosophies built into preventive maintenance, predictive maintenance, real-time monitoring, reactive maintenance, and proactive maintenance to increase the probability that an asset will perform in the desired manner over its intended design life. The primary objectives of RCM are to maximize asset reliability and minimize life-cycle costs by integrating maintenance approaches rather than applying them independently. By focusing on reliability and costs throughout the life of an asset, RCM directly supports the practice of life-cycle planning for asset management. The three main components of an RCM program that are most relevant to life-cycle planning of ancillary highway assets are condition-based maintenance, interval-based maintenance, and reactive maintenance (see figure 16).

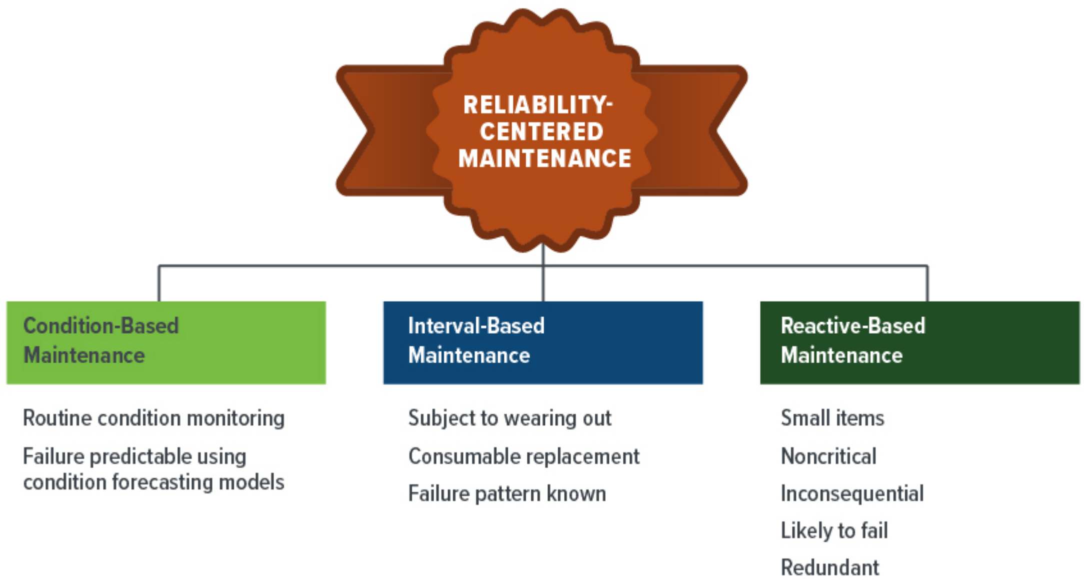


Figure 16. Graphic. Components of an RCM program (adapted from NASA 2008).

RCM Application to the Transportation Industry

The maintenance approach for assets such as pavements and bridges, which are being managed using relatively mature management systems, may be based on a predictive monitoring approach. Routine asset condition surveys provide information on current condition and the time-series condition data can be used to develop forecasting models that predict when the assets will need a specific type of maintenance activity. Assets such as ITS devices and traffic signals may need a different approach, requiring a regular replacement cycle based on historical performance or the service life estimated by the manufacturer. These assets may be more suited to an interval-based maintenance approach. Other roadway assets, such as raised pavement markers, may require replacement only when they fail to perform their intended function, and hence a reactive maintenance approach may be the preferred strategy.

RCM Process for Ancillary Assets

The first step is to define the function and associated performance standards for the asset. In addition to the primary function of the asset, there are several secondary functions including, but not limited to, safety, environmental, appearance, containment, and/or economy. The DOT needs to assign where, when, and under what conditions the asset will operate and what will be the performance standards. It is possible for an asset to have a functional or partial failure that allows the asset to remain in service with reduced capabilities. A total failure would render the asset out of service (e.g., sign falling from mounting, retaining wall slope stability failure, guardrail demolished by natural or man-made disaster). After defining the failure modes and potential impacts, the RCM process asks what can be done to prevent or predict the failure. The results of the failure modes and effects analysis (FMEA) leads to the three possible outcomes introduced earlier: condition-based, interval-based, or reactive maintenance. Figure 17 shows a decision-logic tree that can be used in determining the most suitable maintenance approach for ancillary assets.

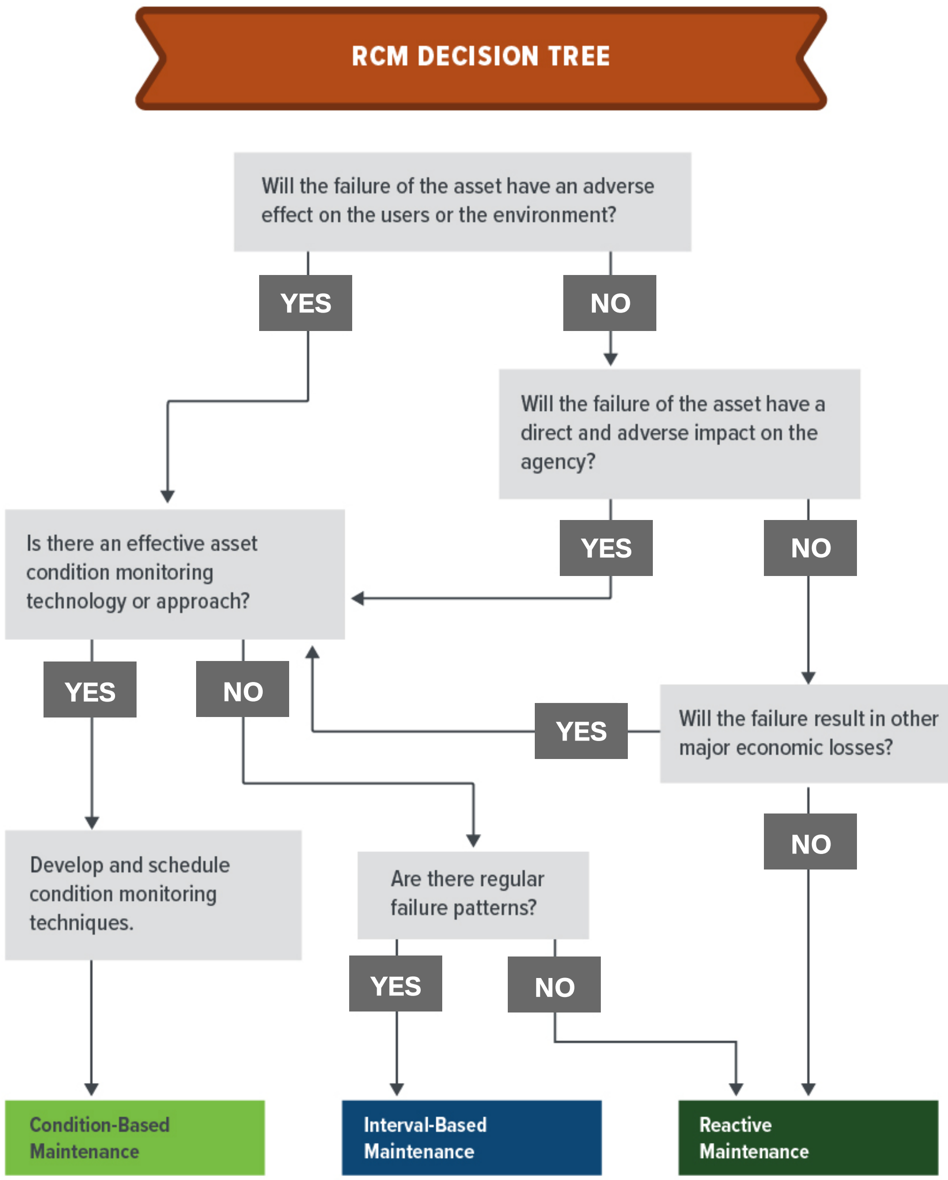


Figure 17. Graphic. Reliability-centered maintenance (RCM) decision tree (adapted from NASA 2008).

Examples are provided below demonstrating how two State DOTs have applied the RCM process to select maintenance approaches for ancillary assets. Indiana DOT determined that high-mast light poles were best managed through condition-based maintenance, while Nevada DOT determined that ITS assets were best managed through interval-based maintenance.

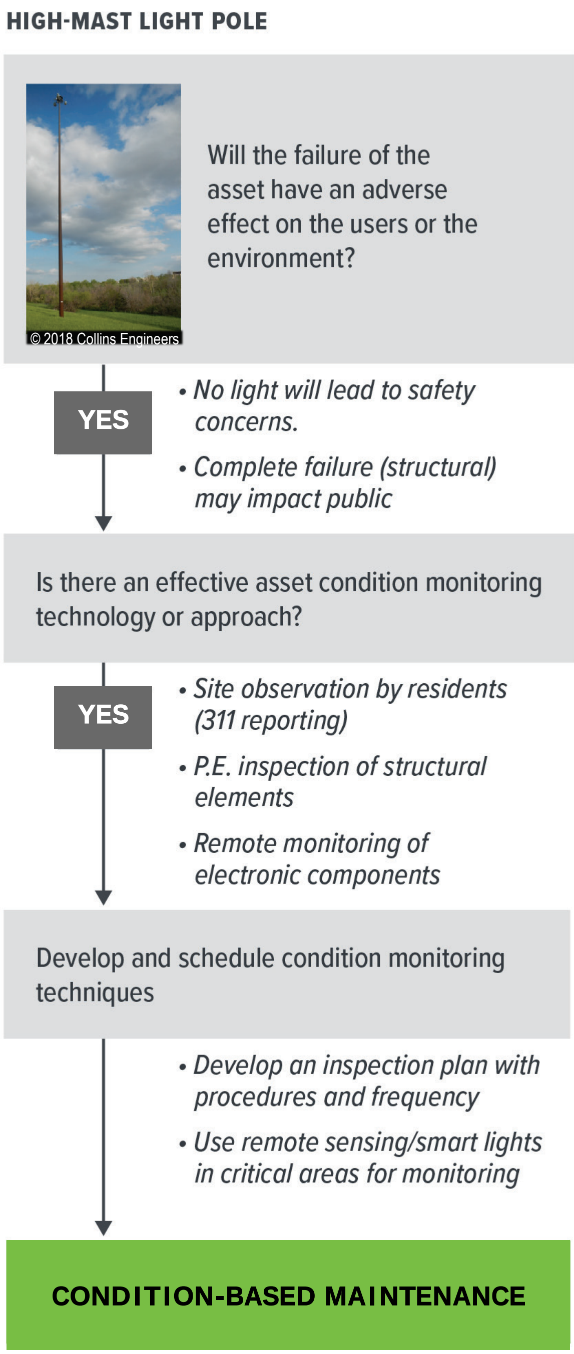


Figure 18. Graphic. Example of applying the RCM decision tree—condition-based result.

Condition-Based Maintenance Example–High-Mast Light Pole

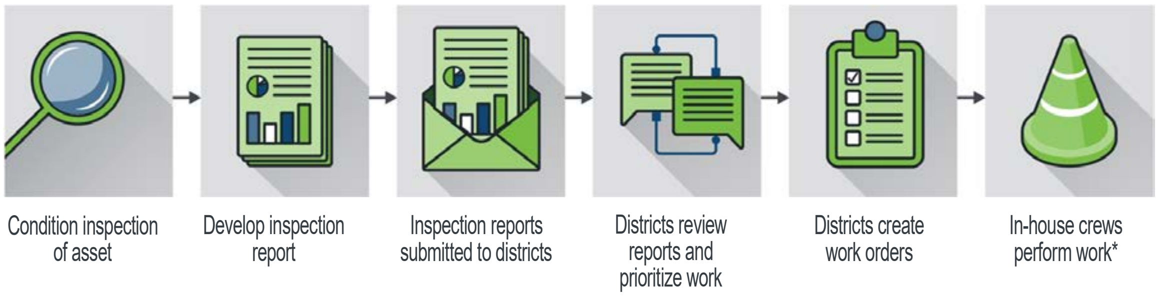
Condition-based maintenance includes predictive maintenance and real-time monitoring. Infrastructure assets typically have inspection schedules prescribed by national standards. The inspector noting the maintenance requirements in the recommendation segment of the condition survey eases the workload on the maintenance department to only repair and replace assets that require attention, not those that are still within their useful life.

An example of condition-based maintenance is the high-mast light pole that provides lighting pointed toward the ground to ensure the safety of the traveling public. The functional failure of this asset occurs if one or more of the bulbs in the light do not work. Alternately, a complete failure occurs if the pole itself falls due to the connection at the foundation, poor installation, the material for the pole does not meet material specifications, or some other unforeseen failure mechanism occurs. The questions and answers shown in figure 18 illustrate the use of the RCM decision tree.

The Indiana Department of Transportation (INDOT) has been performing condition-based maintenance for its overhead sign structures for the past several years, as described in figure 19.

NOTEWORTHY PRACTICE

The Indiana Department of Transportation (INDOT) has been performing condition-based maintenance for their overhead sign structures for the last 8 years. In general, the process is as follows:



*If in-house crews are unable to perform work, it may get contracted out to a local contractor.

Figure 19. Graphic. Condition-based maintenance approach for sign structures used by INDOT.

This process has been working well for INDOT and has led to the identification of several goals, including:

1. Improve tracking of maintenance work to be performed.
2. Increase collaboration between districts within the agency.
3. Improve the prioritization and tracking of major repairs and replacements.
4. Execute an indefinite duration indefinite quantity (IDIQ) contract to expedite the delivery of work by contractors.

Interval-Based Maintenance

Interval-based maintenance is performed without regard to the asset condition and consists of regularly scheduled inspections or replacements. An example of an asset managed using interval-based maintenance is ITS traffic cameras. The purpose of the ITS traffic cameras is to observe vehicular traffic on the roadway. The functional failure of this asset occurs if the camera stops taking images. Figure 20 illustrates the approach used by the Nevada Department of Transportation (NDOT) to manage its ITS traffic cameras. A more complete description of Nevada DOT's approach to manage its ITS assets follows.

NEVADA DOT'S INTERVAL-BASED MAINTENANCE APPROACH

The Nevada DOT (NDOT) has adopted an interval-based approach to maintain its ITS devices. This approach uses age data and manufacturer recommendations to establish asset conditions and replacement cycles. This approach is expected to provide better conditions for lower cost than a worst-first reactive strategy.

Nevada DOT has been rapidly expanding its deployment of ITS devices for many years. These devices are critical to the safe and efficient operations of the agency's highway network. The agency sought a means of managing these assets to minimize the risk of failures impacting traffic operations at a practicable life-cycle cost.

To address the risk of device failure, the agency developed deterioration rates for each subclass of ITS device, based on expert opinion provided by NDOT staff. The deterioration rates typical time over which a device deteriorates from one condition to another, with condition described as the risk of failure (e.g., “good” represents “low risk”). Next NDOT developed lists of appropriate maintenance actions to be performed on assets in each condition state.

Using the deterioration rates, rating system and maintenance-actions, NDOT developed a spreadsheet tool to calculate the cost of performing the maintenance actions within appropriate timeframes and the impact of those actions on asset conditions. Using the spreadsheet, NDOT performed a 20-year analysis comparing the new interval-based strategy to the old reactive strategy of replacing devices when they fail. The results of this analysis showed that to maintain similar conditions, the interval-based strategy would cost 56 percent less ($1.1 million) than the reactive strategy. NDOT has since incorporated the interval-based strategy into its TAMP and programming practices. Figure 21 shows the matrix of deterioration rates and maintenance actions NDOT developed as part of its interval-based maintenance approach.

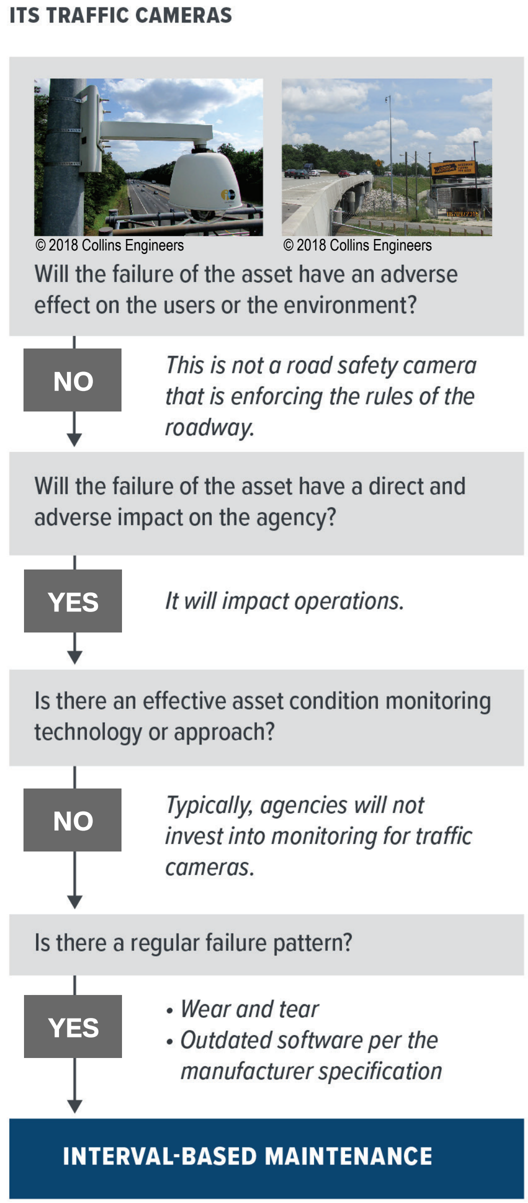


Figure 20. Graphic. Example of applying the RCM decision tree—interval-based result.

Reactive Maintenance

Reactive maintenance assumes that failure is not detrimental to the operation of the asset. It is typically applied where there are no effective monitoring approaches to assist the agency, and/or there are no regular deterioration or failure patterns. Therefore, this maintenance method is to repair after the failure. Budgeting for reactive maintenance activities may be planned by estimating the failure event frequency based upon historical data.

Current Condition	Resulting Condition After Inspection	Resulting Condition After Minor Repair	Resulting Condition After Major Repair	Resulting Condition After Replacement
Good	Good	–	–	–
Low Risk	Low Risk	Good	–	–
Medium Risk	Medium Risk	Medium Risk	Low Risk	–
High Risk	High Risk	High Risk	Medium Risk	Good

Good: Device age is less than 80 percent of the manufacturers' recommended service life.
Low Risk: Device age is between 80 to 100 percent of the manufacturers' recommended service life.
Medium Risk: Device age is between 100 to 125 percent of the manufacturers' recommended service life.
High Risk: Device age is greater than 125 percent of the manufacturers' recommended service life.
-n/a

Figure 21. Graphic. Nevada DOT's maintenance approach for ITS assets (NDOT 2018).

Application of RCM Decision Tree to Ancillary Assets

The RCM decision tree is applied to a generally accepted asset classification hierarchy, which categorizes the assets by asset class, asset elements, and then sub-elements to help the agency manage the information (Rose et al. 2014). The user should clearly define and document the higher-level goals of the agency and how these are supported by each asset element as the RCM decision tree is applied. Table 5 presents a summary of the applicability of condition, interval, or reactive maintenance for each of the asset classes.

Table 5. Categorization of applicable maintenance approaches by asset class.

a. Structures (not Bridges or otherwise in the national bridge inventory).

ASSET ELEMENTS	CONDITION BASED	INTERVAL BASED	REACTIVE BASED
Drainage structures	Preferred	Not recommended	Feasible
Overhead sign and signal structures	Preferred	Not recommended	Feasible
Retaining walls (earth retaining structures)	Preferred	Not recommended	Feasible
Noise barriers	Preferred	Not recommended	Feasible
Sight barriers	Preferred	Not recommended	Feasible
High-mast light poles	Preferred	Not recommended	Feasible

b. Traffic control and management—active devices.

ASSET ELEMENTS	CONDITION BASED	INTERVAL BASED	REACTIVE BASED
Signals	Feasible	Preferred	Feasible
ITS equipment	Feasible	Preferred	Feasible
Network backbone	Feasible	Preferred	Feasible

c. Traffic control and management—passive control devices.

ASSET ELEMENTS	CONDITION BASED	INTERVAL BASED	REACTIVE BASED
Signs	Feasible	Feasible	Preferred
Guardrail	Feasible	Feasible	Preferred
Guardrail end treatments	Feasible	Feasible	Preferred
Impact attenuator	Feasible	Feasible	Preferred
Other barrier systems	Feasible	Feasible	Preferred

d. Drainage systems and environmental mitigation features.

ASSET ELEMENTS	CONDITION BASED	INTERVAL BASED	REACTIVE BASED
Drain inlets and outlets	Feasible	Preferred	Feasible
Culverts (<20 ft. total span)/pipes	Preferred	Feasible	Feasible
Ditches	Feasible	Preferred	Feasible
Stormwater retention systems	Feasible	Preferred	Feasible
Curb and gutter	Feasible	Preferred	Feasible
Erosion control	Feasible	Preferred	Feasible
Other drains	Feasible	Preferred	Feasible

e. Other safety features.

ASSET ELEMENTS	CONDITION BASED	INTERVAL BASED	REACTIVE BASED
Lightning	Feasible	Feasible	Preferred
Pavement markings	Feasible	Feasible	Preferred
Rockfall	Feasible	Feasible	Preferred

f. Roadside features.

ASSET ELEMENTS	CONDITION BASED	INTERVAL BASED	REACTIVE BASED
Sidewalks	Feasible	Feasible	Preferred
Curbs	Feasible	Feasible	Preferred
Fence	Feasible	Feasible	Preferred
Turf	Feasible	Feasible	Preferred
Brush control	Feasible	Feasible	Preferred
Roadside hazard	Feasible	Not recommended	Preferred
Landscaping	Feasible	Preferred	Feasible
Access ramps	Feasible	Preferred	Feasible
Bike paths	Feasible	Preferred	Feasible

g. Other facilities and other items.

ASSET ELEMENTS	CONDITION BASED	INTERVAL BASED	REACTIVE BASED
Rest areas	Preferred	Feasible	Feasible
Weigh stations	Preferred	Feasible	Feasible
Parking lots	Feasible	Preferred	Feasible
Buildings	Preferred	Feasible	Feasible
Fleet	Feasible	Preferred	Feasible
Roadside graffiti	Feasible	Feasible	Preferred
Roadside litter	Feasible	Preferred	Feasible

IDENTIFY DATA TO SUPPORT DECISION-MAKING

DATA NEEDS

Define maintenance approach

χ Identify data to support decision-making

Optimize data collection

Data-driven decisions rely on asset data to make effective investment decisions. Good data collection practices will enable an agency to perform strategic RCM maintenance and enable efficient work order distribution. With the appropriate data, metrics can be derived, and performance measures can be compared to verify whether a maintenance approach is working effectively and how it might be improved. Asset data can be classified as being either essential or desirable. Regardless of which type of data is being collected, it is important that the data is complete and reliable.

Using data to manage assets requires that decision makers understand and trust the data they are using. A data dictionary defines each of the asset attributes needed. Development of a data dictionary prior to selecting a data collection approach will ensure consistency in the data collection process and can also help in agency-wide data integration, as discussed in Chapter 5. A data dictionary typically describes the attributes that are to be collected, the level of detail necessary, and the level of accuracy that is expected. An excerpt from a sample data dictionary from the Tennessee DOT is shown in figure 22.

ATTENUATORS

Energy-absorbing barriers that provide protection from vehicles striking rigid bodies such as bridge columns and barrier walls

LRS to reference	Log mile location of front nose of attenuator
GPS to reference	GPS location of front nose of attenuator
Feature type	04
Feature characteristics: Choose from the following types	00758 – GREAT 00759 – TRACC 00760 – Quadguard 00761 – Hex-foam sandwich 00762 – React 01330 – TAU-II 01331 – SCI 01332 – HEART 013333 – QUEST
Feature location: Choose from the following locations	1 – Left 2 – Right 4 – Median Right 6 – Median Left 7 – Centerline
Height	Report tallest height to nearest 0.1 feet Measure vertically from the ground to the top of the attenuator
Width	Report widest point to nearest 0.1 feet

Figure 22. Graphic. Sample data dictionary for impact attenuators (TDOT 2014).

Essential Data

For any type of RCM practice, it is important to be able to identify individual assets efficiently and consistently within the enterprise. To do this, there are some basic data attributes that are essential to adequately execute maintenance activities. Basic essential data attributes include the type of asset, location of the asset, and a unique identifier (asset ID). There may be other data attributes that an agency deems essential that could be subcategories of the data elements listed above or completely different attributes. It is up to the agency to determine what data attributes are essential to their needs.

If asset data is being used or modified by multiple business units, it is paramount that there are data governance rules established because there can only be one source of truth for data. For example, if a department within an agency is maintaining data for a high-mast light pole through multiple departments, such as a structures department and a lighting department, then there should only be one name for the type of asset (high-mast light pole), one location, and one asset ID. Table 6 summarizes the essential data used for various RCM maintenance approaches.

Table 6. Essential data to collect for the RCM maintenance approaches.

MAINTENANCE TYPE SUPPORTED	ASSET TYPE	ASSET LOCATION	ASSET UNIQUE ID	CONDITION DATA
Interval-based maintenance	X	X	X	-
Reactive-based maintenance	X	X	X	-
Condition-based maintenance	X	X	X	X

Asset Class and Subgroup

Identifying the asset class, and subgroup as necessary, is essential to supporting asset management decisions because assets that serve the same function but have different attributes are often maintained differently. The asset class should always fall within one of the predetermined asset types within the agency. In other words, an agency should define a complete list of assets that ensures all the agency's assets fit within one of these asset classes. Agencies may decide to continue to divide assets into levels of subgroups such that assets with similar attributes can be maintained similarly and often more efficiently.

Location

The location of the asset can be determined numerous ways. Some of the more common types of locating assets in the field include using:

- Global Positioning System (GPS) coordinates.
- Latitude/longitude.
- Linear Referencing System (LRS).
- Route and mile points.
- Route, mile points, and offsets.
- Street addresses.
- Intersections.
- Others.

Often agencies will locate an asset with a quantitative method (e.g., LRS or GPS coordinates) and then also use a qualitative method (address or exit number) to assign a common locator that is familiar to agency personnel. As seen in figure 23, the reason for this is that the quantitative method allows for a precise location that is used in a database, mapping software, or asset management system. The qualitative method tends to be better understood by maintenance crews and other agency personnel. For example, if a work order listed only GPS coordinates for the work location, it would not be intuitive for a maintenance foreman to know precisely where to go. If, on the other hand, the location was presented with route and mile point, the maintenance foreman would know exactly where to go. Technology is making the need for the quantitative method less critical since most people currently rely on electronic mapping systems.

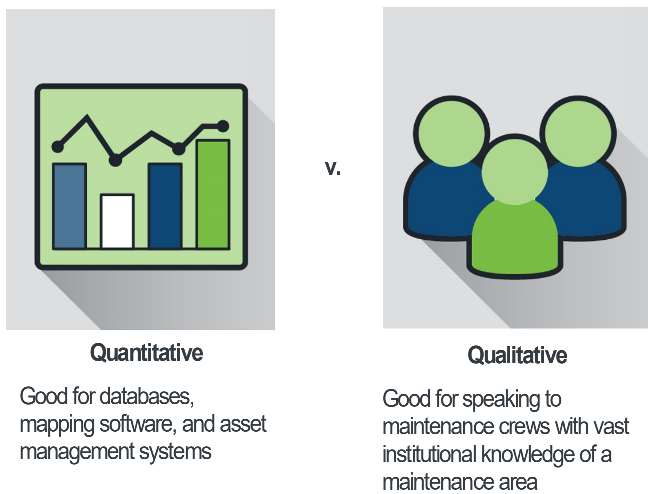


Figure 23. Graphic. Qualitative v. quantitative method for locating assets in the field.

Unique Identifier

To identify each asset separately and to ensure the correct asset is being maintained, it is essential to have a unique identifier (or asset ID) for each asset within the inventory. This is very simple to understand, but its importance cannot be understated. This becomes even more critical when using a database or electronic asset management system as these systems require a unique identifier for each asset in the system. Having a unique asset ID, visible to the user, also makes it easier to address maintenance work orders so that there is no confusion on the asset being worked on.

Condition

In a condition-based maintenance approach, there is at least one additional piece of data that is essential: asset condition. This can be collected and displayed in numerous ways. It can be one value—number, letter, word, and so on—or can be numerous values representing the different components or functionalities within the asset. Often it is simplest to designate one value representing the overall health index of the asset, which may be a culmination of smaller asset element values. The evaluation scale for condition can be represented numerous ways, such as:

- Number scale: 1 to 10, 10 to 1, 1 to 100, 100 to 1, etc.
- Low value (good) to high value (poor).
- Low value (poor) to high value (good).
- Letter scale: A (good) to F (poor).
- Word scale: good, fair, poor.
- Color scale: Green (good) to Red (poor).

It is easiest to compare assets to one another when different assets use the same condition scale. However, based on the age of a program, the existence of legacy systems, the importance of assets, and the number of stakeholders involved, it is not always practical to use the same rating system for each asset.

In condition-based maintenance, it is important to distinguish between functional and structural condition. The functional condition pertains to the ability of the asset to perform its intended function. The structural condition is an assessment of the reliability of the component or asset to remain in place without risk of endangering the public, the agency's reputation, existing property, or the environment. For example, if a traffic signal is malfunctioning and the signal head is not working, then this is a scenario of poor functional condition and may increase the risk of an accident to the traveling public. An example of poor structural condition is if a traffic signal pole is severely corroded at the base: this may increase the risk of the pole falling into the intersection, causing an increased risk of harming the traveling public, the agency's reputation, and/or property. In condition-based maintenance, it is desirable to maintain good functional and good structural condition.

Desirable Data

In addition to the essential data needed to support a maintenance program, there is likely a significant amount of additional data that is desired for any given type of asset. There are many reasons for collecting additional data. As noted below, the additional data may:

- Provide additional clarity and accuracy to the essential data collected.
- Support different departments within an agency.
- Assist in generating accurate work orders.
- Help manage asset risks.
- Track the asset's full life cycle to make informed decisions.

The above list is not all-inclusive but provides clear examples of reasons why additional data collected in the field could be beneficial to an agency. Each of these items is described in more detail below.

Other desirable data attributes that are not described further may include (HMEP 2013):

- Maintenance intervals.
- Frequency of failure.
- Allocated risk factors.
- Maintenance requirements.
- Engineering specific data.

Provide Additional Clarity and Accuracy to the Essential Data Collected

As discussed earlier, it can be beneficial and desirable to collect essential data (such as location information) in more than one format. It can be important to collect location data for use in an electronic system in GPS or latitude/longitude format, but route and mile point data might also be useful for maintenance crews and other agency personnel. The GPS or latitude/longitude data is generally more accurate and more easily maintained in a data set, but the route and mile point data are easier to describe to a maintenance crew member. BIM for infrastructure is enabling agencies to support systems that easily translate between location systems. This technology allows the data to be provided to each user in the most appropriate form. For example, integrated MMSs that can display work orders in a mobile mapping environment locate an asset on a map with routing directions built into the system, even if the location stored for that asset in the database is in Latitude/Longitude coordinates.

Condition data is another example where it often may be desired to collect additional data. For condition-based maintenance, it is important to know the overall condition of an asset. However, it may be even more beneficial to know the condition of various asset elements. For example, if a 100-foot-long retaining wall is in poor condition overall but there is a support element in the middle of the structure that is driving the poor condition, that information would be useful for planning maintenance needs. In this example, instead of slating an entire structure for replacement, the maintenance crews may be able to fix the poor component and leave the remaining portion of the structure in service.

Support Different Departments within an Agency

It is quite common that different business units within an agency have an interest in the same asset but for different reasons. For an overhead sign, the traffic unit may be interested in the actual sign, while the bridge and structures units may be interested in the condition of the structure supporting the sign. If there is electricity running to the site, then perhaps the electrical department has an interest in the asset, and if there is a variable message sign or dynamic message sign mounted to the structure, then the ITS group may also be interested in the asset. In these cases, the various entities would likely all have different data needs to describe the asset, its condition, and its functionality. Whenever different departments within the agency are collecting data on the same assets, it is critical to develop a data dictionary and establish data governance rules for managing the data. Chapter 5 presents more information on how BIM for infrastructure can integrate data across IT systems and business units.

Assist in Generating Accurate Work Orders

Accurate work orders are important to ensure that an MMS accurately reflects work accomplishments and maintenance needs. Often, only elements or components of an asset are replaced or repaired. Knowing the type of work that will be needed enables maintenance crews to bring the correct equipment, tools, and materials to the site, helping to avoid wasteful trips between the garage and the work site. Even if the entire asset is going to be replaced, some basic data on the existing type, size, and model would typically make it easier to repair or completely swap out assets.

Help Manage Asset Risks

Evaluating risks requires more information than knowing the location and condition of an asset. Risk is the product of likelihood and consequence of failure. It can be influenced by numerous factors, such as age, asset type, asset material, and design parameters. Risks can also be skewed if only average condition information is available because a component with a high-risk failure potential could be masked if the rest of the asset is in good condition.

Track the Full Asset Life Cycle to Make Informed Decisions

By collecting additional data, an agency can begin to manage maintenance activities over the full asset life cycle. This type of data can include asset age, work history, and inspection history. With this information, agencies are better prepared to evaluate whether it is cost-effective to maintain an asset or whether more expensive repairs are necessary.

OPTIMIZE DATA COLLECTION

Decision-making for the maintenance and operation of transportation assets is primarily dependent on available inventory, condition, and maintenance data. Data collection methods have transformed considerably over the years due to advances in technology. The use of automated data collection equipment has not only increased the data collection and processing speeds, but it has also provided the ability to collect a wide range of data for multiple assets using the same equipment with minor adjustments.

DATA NEEDS

Define maintenance approach

Identify data to support decision-making

X **Optimize data collection**

The ability to make sound investment decisions relies on the following (Zimmerman and Manda 2015):

- Availability of a comprehensive asset inventory.
- Method of assessing current conditions and performance.
- Tools for evaluating the impacts of different investment strategies on system performance.

The development of an asset inventory is the first step in establishing a strong asset management program. This section describes the various data collection approaches to support the development of an asset inventory database. The key steps involved in the data collection process are also discussed. The scope of this section is limited to the approaches, processes, and generic protocols related to ancillary transportation assets maintained by State DOTs, such as overhead sign structures, guardrails, high-mast tower lighting, and ITS devices.

Much of the information presented in this section has been adapted from The NCHRP Project 20-07/Task 357 *A Guide to Collecting, Processing, and Managing Roadway Asset Inventory Data* (Zimmerman and Manda 2015). Background information and additional details for much of the information presented in this section are in the NCHRP report cited above.

Data Collection Approaches

The information provided in this section focuses on the use of three types of data collection techniques/technologies: manual techniques and two types of automated techniques, photogrammetry and mobile LiDAR.

Manual Techniques

Manual data collection techniques involve the collection of assets by staff at the asset's location. There are three general types of manual data collection: nondestructive testing, destructive testing, and remote sensing. The manual data collection process typically involves one or more surveyors/raters collecting the data using one or more of the following methods:

- Record inventory and condition information using a pencil and paper.
- Utilize Global Position System (GPS) technology to locate assets in the field.
- Use handheld computers, tablets, or mobile phones to record field data.

Figure 24 summarizes some key characteristics associated with manual data collection.

Figure 24. Graphic. Characteristics associated with manual data collection techniques (adapted from Zimmerman and Manda 2015 with permission from National Academy of Sciences, courtesy of the National Academies Press, Washington, DC).

Automated Techniques

Automated data collection techniques involve the use of a specially equipped vehicle at near-traffic speeds to collect asset data. The two popular automated data collection techniques used for establishing highway asset inventories are photogrammetry and mobile LiDAR.

PHOTOGRAMMETRY

Photogrammetry typically involves the use of laser sensors to monitor pavement surface characteristics (such as rutting or roughness) and digital cameras strategically mounted on the vehicle to capture various roadway features (e.g., signs, signals, curb and gutter, etc.) that are visible from the right-of-way. The main characteristics associated with photogrammetry-based data collection are shown in figure 25.

PHOTOGRAMMETRY

DATA COLLECTION AND PROCESSING

Data can be collected at the same time as data for other applications by adding a ROW camera and other specialty-positioned cameras. The surveys are conducted at traffic speeds.

- Asset inventory is created by extracting data from a data processing interface usually licensed by the equipment manufacturer.
- Little to no expertise required to build an inventory.
- Data are convenient and accessible—for example, data can be extracted a year after the surveys were conducted if resources are not available prior to that.

APPLICATION

Can be used to inventory all roadway assets visible from the roadway.

Data can be collected for multiple assets simultaneously at highway speeds.

VALUE ADDED

VALUE ADDED!

Increases consistency by limiting the amount of human intervention.

Images can be reused for multiple purposes with another survey.

Improves safety by reducing the number of personnel in the field.

LIMITATIONS

Accuracy of the roadway asset location may be limited to a few feet.

Dimensions of assets cannot be extracted accurately.

Assets that are not visible from the roadway cannot be inventoried.

Figure 25. Graphic. Characteristics associated with photogrammetric data collection techniques (adapted from Zimmerman and Manda 2015 with permission from National Academy of Sciences, courtesy of the National Academies Press, Washington, DC).

MOBILE LIDAR

Some data collection vehicles are equipped with remote-sensing technology to measure distances by analyzing the reflected light from an asset after being lit by a laser. This technology is commonly referred to as mobile LiDAR. Mobile LiDAR can locate objects in the field to a high precision level, from 3 inches up to a range of around 250 feet. A 3-D point cloud that can be used in determining offsets or measuring vertical distances is then generated. As with photogrammetry, this technique is limited to the assets visible from the ROW and within the range of the imaging devices used. Figure 26 summarizes some of key characteristics associated with mobile LiDAR.

MOBILE LIDAR

DATA COLLECTION AND PROCESSING

LiDAR is a remote sensing technology that collects data in 3-D point clouds. Data are captured by a van driven at traffic speeds with a LiDAR sensor mounted on top and paired with a scanner, photo detector, and GPS. The equipment can be coupled with lasers and cameras for other applications, such as pavement condition surveys.

- Data are extracted from a data processing interface usually licensed by the equipment manufacturer.
- Specialized expertise is beneficial to effectively manage the data.
- Survey images can be used later to inventory a new asset without resurveying.
- The process becomes increasingly more cost-effective as the number of applications for the data increases.

APPLICATION

Can be used to inventory all roadway assets visible from the roadway.

Data can be collected for multiple assets simultaneously at highway speeds.

VALUE ADDED

VALUE ADDED!

Assets can be located accurately to within a few inches.

Vertical clearances and dimensions can be estimated within a few inches.

Increases consistency by reducing human intervention.

Point cloud can be reused for multiple purposes without resurveying.

Improves safety by reducing personnel in the field.

LIMITATIONS

LiDAR by itself does not capture objects in color, which may be used to classify some assets (such as signs).

Assets that are not visible from the roadway cannot be inventoried.

Figure 26. Graphic. Characteristics associated with Mobile-LiDAR data collection techniques (adapted from Zimmerman and Manda 2015 with permission from National Academy of Sciences, courtesy of the National Academies Press, Washington, DC).

A summary of the key considerations in selecting the most suitable data collection methodology for highway assets is provided in figure 27.

MANUAL DATA COLLECTION	PHOTOGRAMMETRY	MOBILE LIDAR
Fair degree of accuracy (± a few ft.) Labor intensive Safety issues with personnel in the field Quality control activities require additional personnel in the field Best option for inventorying assets not visible from the road Does not require specialized technical expertise or equipment Most applicable when collecting a limited amount of data	Good accuracy (±1 ft.) Not labor intensive Requires specialized equipment Operates at traffic speeds Can only be used to inventory assets from the road Easily used in conjunction with automated pavement condition surveys Data can be used by multiple Divisions within an agency Quality control activities can be done at a workstation Requires some technical expertise	High degree of accuracy (±3 in.) Not labor intensive Requires special equipment Operates at traffic speeds Can only be used to inventory assets visible from the road Provides features for estimating assets' dimensions Easily used in conjunction with automated pavement condition surveys Data can be used by multiple Divisions within an agency Quality control activities can be done at a workstation Provides greatest benefit when data are used by multiple Departments Requires specialized technical expertise Generates large data files that must be managed

Figure 27. Graphic. Factors in selecting a methodology for building an asset inventory (adapted from Zimmerman and Manda 2015 with permission from National Academy of Sciences, courtesy of the National Academies Press, Washington, DC).

Other Data Collection Techniques and Emerging Technologies

There are other methods of manual data collection that are less common but can be very practical:

- **Nondestructive Evaluation (NDE)**: NDE provides the ability to collect data on an asset while not disturbing or destroying the asset's condition or physical properties. There are dozens of different types of NDE available, and they all typically require training and certification to be used properly and reliably in the field. Examples of NDE include ultrasonic testing, radiography, dye penetrant, impact echo, and acoustic emissions. Other types of NDE can be found at FHWA's website: https://fhwaapps.fhwa.dot.gov/ndep/TechnologyMenu.aspx (FHWA 2015).
- **Remote Sensing**: Another method of data collection is remote sensing. With remote sensing, condition data is typically collected and stored in a computer onsite with the asset or the data transmitted to the agency for collection and storage. Remote sensors can be

used to monitor flow or scour in a culvert, movement of a retaining wall, or the propagation of a fatigue crack in a high-mast light tower. Sometimes a combination system containing NDE and remote sensing may be engaged to most efficiently monitor high vulnerability areas on an asset.
- **Destructive Testing**: This another method of testing to obtain data, but as the name suggests, there will be some destruction to the asset or component, albeit typically insignificant. Testing such as concrete cores and steel coupons are examples of destructive testing.

Emerging Technologies

Some of the promising techniques that are currently either in the development phase or undergoing feasibility testing for potential use in highway asset data collection are summarized in this section:

- **360-Degree Camera**: These cameras consist of six lenses to provide a 360-degree horizontal perspective of a selected area. The images from each of the cameras are stitched together using image processing algorithms to provide a seamless 360-degree view of the photographed areas. One of the six cameras is positioned vertically to generate a spherical view of the area. This technology can potentially be useful in monitoring areas such as intersections and interchanges.
- **Flash LiDAR**: Flash LiDAR, also referred to as a time-of-flight (TOF) camera, illuminates the whole area of interest at once, as opposed to mobile LiDAR, in which every single point is illuminated with a laser. Each pixel in the image generated provides an indication of the time elapsed between the instant that the camera's laser flash pulse hits the targeted asset and the instant it bounces back to the cameras focal plane. The resulting output is a 3-D image from depth measurements for each point on the asset. Flash LiDAR is currently being tested for applications in the military and automobile industry.
- **Airborne LiDAR**: Aerial or airborne LiDAR techniques have been around for several years, but airborne LiDAR's use has been limited by the Federal Aviation Administration's (FAA) restrictions imposed to avoid conflicts with air traffic. Airborne LiDAR is more useful as a planning and design tool rather than building highway asset inventories. These techniques have been used on large projects to assist with grading, utilities, drainage analysis, erosion control, and roadway designs.

Steps in Data Collection

Asset data collection and management activities can be organized into a four-step process (Zimmerman and Manda 2015). The key considerations in the first three steps, illustrated in Figure 28, are described in this chapter. The considerations under step 4 are discussed in chapter 5.

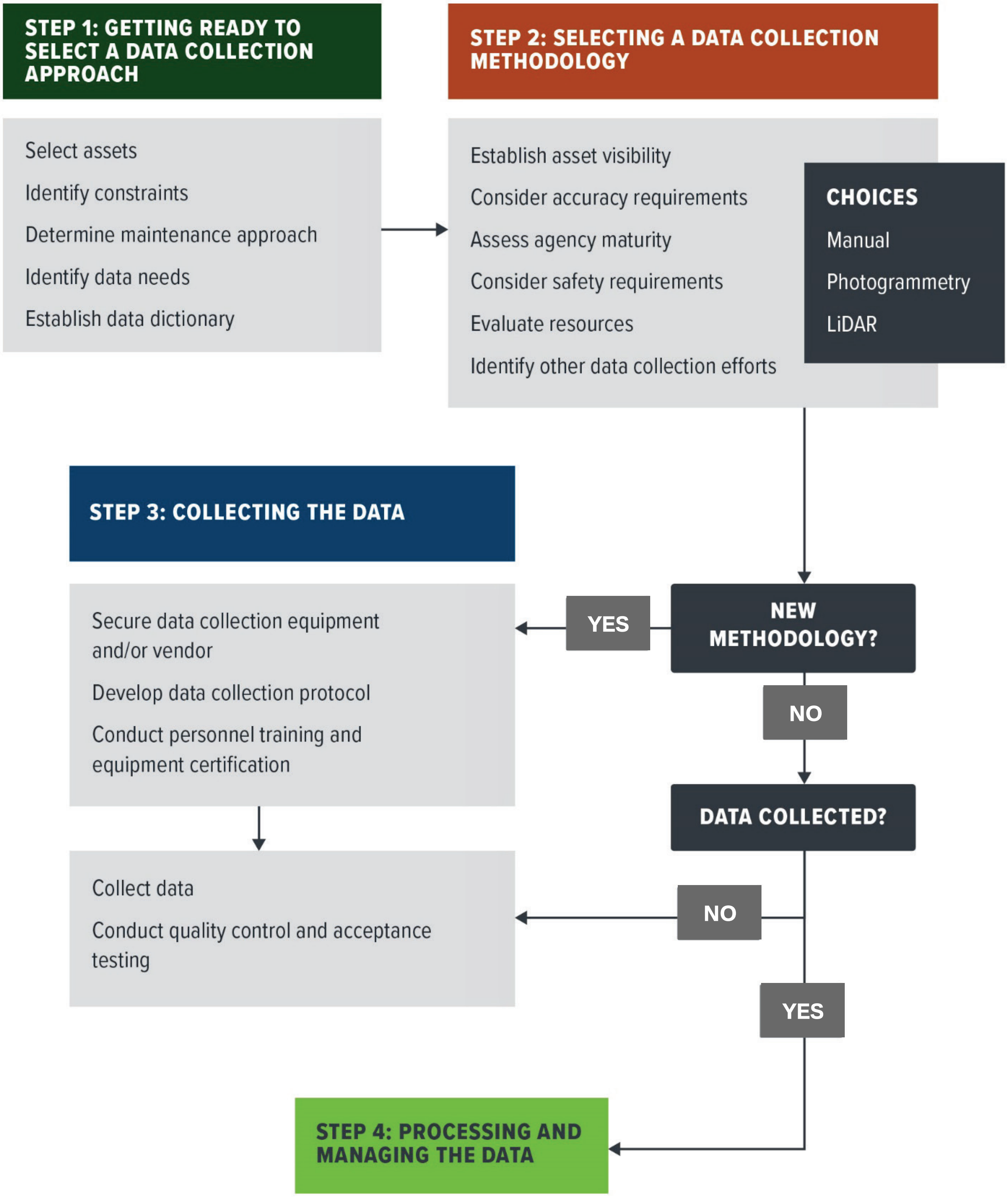


Figure 28. Graphic. Steps for developing or updating a highway asset inventory (adapted from Zimmerman and Manda 2015 with permission from National Academy of Sciences, courtesy of the National Academies Press, Washington, DC).

Step 1: Getting Ready to Select a Data Collection Approach

Prior to an approach for data collection, an agency needs to understand the characteristics and the intended function of the assets on which data is to be collected, identify fiscal or other constraints that need to be considered, determine the maintenance approach to be used for the asset, and identify the data needs for maintenance approach selected.

Step 2: Selecting a Data Collection Approach

Once the asset(s) to be included in the inventory have been selected and constraints and data needs have been identified and understood, an agency can then start working on selecting the most suitable data collection approach. Tables 7, 8, and 9 show the applicability of manual, photogrammetry, and LiDAR data collection to different types of assets that are being managed through different RCM approaches.

Pierce, McGovern, and Zimmerman (2010) summarize key data collection protocols/related issues/processes/activities that should be documented. These items are listed below:

- Protocols to be used for collecting the data (e.g., resolution of cameras to be used, type of sensors to be used, desired level of accuracy, etc.).
- Deliverables that will be provided to the agency.
- Quality control process to ensure an accurate and repeatable process.
- Acceptance testing to determine whether the quality criteria have been met and corrective actions to be taken if criteria are not met.
- Roles and responsibilities for each personnel involved in the data collection process.
- Verification that all parties involved in the process understand their roles and responsibilities.
- Maps showing locations of assets to be included in the survey along with data formats.
- Troubleshooting guide for field personnel.

Table 7. Applicability of data collection methodologies for inventorying ancillary assets (adapted from Zimmerman and Manda 2015).

a. Structures (not Bridges or otherwise in the national bridge inventory).

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Drainage structures[2]	Preferred	Varies	Varies
Overhead sign and signal structures[3]	Feasible	Feasible	Preferred
Retaining walls (earth retaining structures),[4]	Feasible	Feasible	Preferred
Noise barriers	Feasible	Feasible	Preferred
Sight barriers	Feasible	Feasible	Preferred
High-mast light poles	Feasible	Feasible	Preferred

b. Traffic control and management—active devices.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Signals	Feasible	Feasible	Preferred
ITS equipment[5]	Feasible	Preferred	Preferred
Network backbone	Preferred	Feasible	Feasible

c. Traffic control and management—passive devices.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Signs	Feasible	Preferred	Feasible
Guardrail	Feasible	Feasible	Preferred
Guardrail end treatments	Feasible	Feasible	Preferred
Impact attenuator	Feasible	Feasible	Preferred
Other barrier systems	Feasible	Feasible	Preferred

d. Drainage systems and environmental mitigation features.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Drain inlets and outlets	Preferred	Varies	Varies
Culverts (<20 ft. total span)/pipes	Preferred	Varies	Varies
Ditches	Preferred	Varies	Varies
Stormwater retention systems	Preferred	Varies	Varies
Curb and gutter	Feasible	Feasible	Preferred
Erosion control	Preferred	Feasible	Feasible
Other drains	Preferred	Varies	Varies

[2] May not be visible from the roadway.
[3] Vertical clearances best measured with mobile LiDAR.
[4] The need for dimension data lends them to use of mobile LiDAR.
[5] Automated techniques save time.

e. Other safety features.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Lighting	Feasible	Preferred	Feasible
Pavement markings	Feasible	Varies	Preferred
Rockfall	Preferred	Varies	Feasible

f. Roadside features.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Sidewalks	Feasible	Feasible	Preferred
Curbs	Feasible	Feasible	Preferred
Fence	Feasible	Feasible	Preferred
Turf	Preferred	Varies	Varies
Brush control	Preferred	Varies	Varies
Roadside hazard	Preferred	Varies	Varies
Landscaping	Feasible	Feasible	Preferred
Access ramps	Feasible	Feasible	Preferred
Bike paths	Feasible	Feasible	Preferred

g. Other facilities and other items.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Rest areas	Preferred	Feasible	Feasible
Weigh stations	Preferred	Feasible	Feasible
Parking lots	Feasible	Feasible	Preferred
Buildings	Preferred	Feasible	Feasible
Fleet	Preferred	n/a	n/a
Roadside graffiti	Preferred	Varies	Varies
Roadside litter	Preferred	n/a	n/a

Table 8. Applicability of performance data collection methodologies for ancillary assets utilizing condition-based maintenance (adapted from Zimmerman and Manda 2015).

a. Structures (not Bridges or otherwise in the national bridge inventory).

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Drainage structures	Preferred	Varies	Varies
Overhead sign and signal structures	Preferred	Varies	Varies
Retaining walls (earth retaining structures)	Preferred	Varies	Varies
Noise barriers	Preferred	Preferred	Feasible
High-mast light poles	Preferred	Preferred	Feasible

b. Traffic control and management—active devices.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Signals	Preferred	Preferred	Feasible
ITS equipment	Preferred	Varies	Varies
Network backbone	Preferred	Varies	Varies

c. Traffic control and management—passive devices.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Signs	Preferred	Varies	Varies
Guardrail	Feasible	Varies	Varies
Guardrail end treatments	Feasible	Varies	Varies
Impact attenuator	Feasible	Varies	Varies
Other barrier systems	Preferred	Varies	Varies

d. Drainage systems and environmental mitigation features.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Drain inlets and outlets	Preferred	Varies	Varies
Culverts (<20 ft. total span)/pipes	Preferred	Varies	Varies
Ditches	Preferred	Varies	Varies
Stormwater retention system	Preferred	Varies	Varies
Curb and gutter	Feasible	Feasible	Feasible
Erosion control	Feasible	Feasible	Feasible
Other drains	Feasible	Feasible	Feasible

e. Other safety features.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Lightning	Preferred	Feasible	Feasible
Pavement markings	Feasible	Feasible	Feasible
Rockfall	Feasible	Feasible	Feasible

f. Roadside features.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Sidewalks	Preferred	Feasible	Feasible
Curbs	Preferred	Feasible	Feasible
Fence	Feasible	Feasible	Feasible
Turf	Feasible	Varies	Varies
Brush control	Feasible	Varies	Varies
Roadside hazard	Feasible	Varies	Varies
Landscaping	Feasible	Varies	Varies
Access ramps	Feasible	Feasible	Preferred
Bike paths	Feasible	Feasible	Feasible

g. Other facilities and other items.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Rest areas	Preferred	Feasible	Feasible
Weigh stations	Preferred	Feasible	Feasible
Parking lots	Feasible	Feasible	Feasible
Buildings	Preferred	Feasible	Feasible
Fleet	Preferred	n/a	n/a
Roadside graffiti	Feasible	Varies	Varies
Roadside litter	Feasible	Varies	Varies

Table 9. Applicability of performance data collection methodology for ancillary assets utilizing interval-based maintenance (adapted from Zimmerman and Manda 2015).

a. Structures (not Bridges or otherwise in the national bridge inventory).

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Drainage structures	Preferred	Varies	Varies
Overhead sign and signal structures	Feasible	Feasible	Preferred
Retaining walls (earth retaining structures)	Feasible	Feasible	Preferred
Noise barriers	Feasible	Feasible	Preferred
High-mast light poles	Feasible	Feasible	Preferred

b. Traffic control and management—active devices.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Signals	Feasible	Feasible	Preferred
ITS equipment	Feasible	Preferred	Preferred
Network backbone	Preferred	Feasible	Feasible

c. Traffic control and management—passive devices.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Signs	Feasible	Preferred	Feasible
Barrier systems	Feasible	Preferred	Preferred

d. Drainage systems and environmental mitigation features.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Drain inlets and outlets	Preferred	Varies	Varies
Culverts (<20 ft. total span)/pipes	Preferred	Varies	Varies
Ditches	Preferred	Varies	Varies
Stormwater retention systems	Preferred	Varies	Varies
Other drains	Preferred	Varies	Varies

e. Other safety features.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Lighting	Feasible	Preferred	Feasible

f. Roadside features.

ASSET ELEMENTS	MANUAL	PHOTOGRAMMETRY	LIDAR
Sidewalks	Feasible	Feasible	Preferred
Curbs	Feasible	Feasible	Preferred

Step 3: Collecting the Data

The third step involved data collection using the approach selected and regularly evaluating the process to determine if a different approach may be warranted.

SUMMARY

This chapter discussed the key issues and considerations in selecting the data that needs to be included when an agency decides to move forward with incorporating various ancillary highway assets in its asset management program. The key topics covered include:

- **Reliability-centered maintenance:** Process to determine the most suitable maintenance approach (condition-based, interval-based, or reactive) to manage ancillary assets.
- **Data needs:** Essential and desirable data needed to support reliability-based decision-making.
- **Data collection:** Approaches available to collect asset inventory and condition data and general steps in collecting the data.

The next chapter discusses the key considerations in processing, maintaining, and managing the collected data.

CHAPTER 5. MANAGING ASSET DATA

INTRODUCTION

This chapter presents how an agency can utilize data to support management of the asset through its entire life cycle. BIM for infrastructure, defined in figure 29, is presented as a model framework for storing and sharing data across the organization to support integrated asset management. BIM for infrastructure promotes a philosophy that all asset information, from conception to demolition, should be managed, organized, and shared across the entire highway agency. It also supports the transition from incomplete asset inventories and standalone silos of information to complete, authoritative repositories of agency-wide inventories. This sharing of agency information—including cost, technical (attributes and specifications), project, and program information—allows agencies to effectively manage assets at the lowest cost and to the greatest benefit.

DATA MANAGEMENT

Building Information Management—Agency Data

BUILDING INFORMATION MANAGEMENT (BIM)

BIM is a system of processes for collecting, storing, and exchanging data used to plan, design, construct, operate, and maintain highway infrastructure through the entire life cycle. The key word is *data* — it refers to everything accessible in a single digital environment. Data include not only physical characteristics (assets and attributes) but also functional characteristics (financial, design, specifications, etc.). In BIM, data files can be extracted and exchanged across business units to support decision-making regarding the department's infrastructure in general and assets in particular.

Figure 29. Graphic. Definition of BIM for infrastructure.

THE BENEFITS OF BIM FOR INFRASTRUCTURE

Wise Transportation Stewardship

Transportation agencies in the United States have collectively invested hundreds of billions of dollars in their transportation systems (FHWA 2017). Wise stewardship of the system requires organizations to know where to allocate their limited funds to optimize performance. BIM for infrastructure is a philosophy that promotes the concept that knowledge and information are assets that should be managed.

Implementing BIM for infrastructure requires an agency to think beyond individual data silos and collaborate across the organization. Its foundational concepts encourage collaboration between agency divisions and the reuse of asset data from asset conception to demolition. The goal is for all divisions to collaboratively share authoritative data for a wide range of purposes, including planning, environmental assessment, surveying, design, construction, maintenance, asset management, and risk assessment. By reducing redundant data, systems, and processes, BIM for infrastructure has the potential to produce significant savings in both time and resources.

Integration of data ensures that limited funding is allocated not only based on engineering analysis and judgement but also on the best available information. An agency will, at the same time, improve transparency and public trust. The following guiding principles distinguish BIM from less comprehensive approaches to data management:

- Strategic Plan—Interdepartmental coordination.
- Authoriative Hub—Integrated database and web services.
- Common Data Dictionary—Agency agreement on assets and attributes.
- Business Improvements—Query, analyze, display, and report data.

Figure 30 presents some of the advantages to BIM for infrastructure.

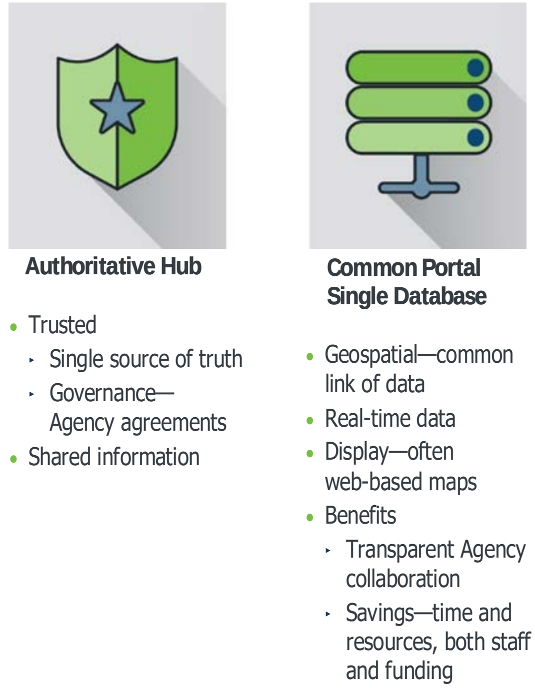


Figure 30. Graphic. Advantages to BIM.

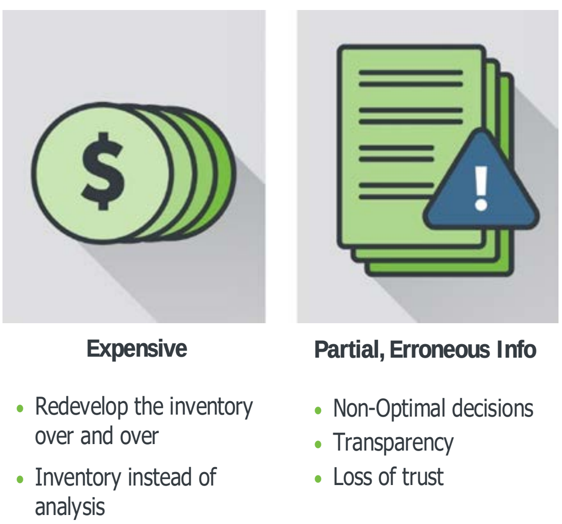


Figure 31. Graphic. Consequences of unknown inventory.

Complete, Authoritative, and Accessible Data

Most transportation agencies have incomplete asset inventories. As shown in figure 31, incomplete inventories and unknown assets can lead to significant consequences for transportation agencies. To establish an inventory, many agencies either drive out to the site or review paper "as built" plans to identify what they own. Documenting the inventory by either method can be expensive, imprecise, and inadequate. Performance-based programs will more readily succeed if the agency establishes data collection standards (known as a Data Dictionary) for creating the inventory and assessing the condition of individual assets.

Compounding the problem of incomplete or inaccurate data is duplicate data, which occurs when several agency business units collect different and often incompatible data about the same assets. An example of this takes place when different business units collect data using different LRSs or note assets with different attributes. The different standards result in assets that are difficult to integrate into the agency's business systems.

Recent improvements in technologies make it possible for agencies to realize complete inventories displayed on web-based maps. Technological improvements include mobile data collection and digital field collection devices with cloud-based mapping applications that enable users to download and upload inventory and display, share, query, and perform analysis from desktops or mobile devices in real time. Agencies now working across functional areas have the capability of geospatially locating every asset "from fencepost to fencepost."

Figure 32 shows how an agency can set up its central data hub (or central repository) to support cradle-to-cradle asset management. The outer ring represents the typical functions: programming, project delivery, operations, and comptroller and performance. This last function covers internal controls and performance management that support all agency functions. The middle ring of circles represents specific agency divisions, such as design, planning, and maintenance. Each division contributes to the total management of an agency asset from planning to design, construction, and operations, and in doing so each group produces and consumes asset data on a day-to-day basis. The goal of the agency should be to have each data element represent a single authoritative source of information, eliminating duplicative and inaccurate data. A key feature illustrated by figure 32 is the middle circle—the data hub or central repository for agency data (including asset data and all project/program, financial, and safety information, for example). The hub provides the agency's location of accessible, shared, and trusted information.

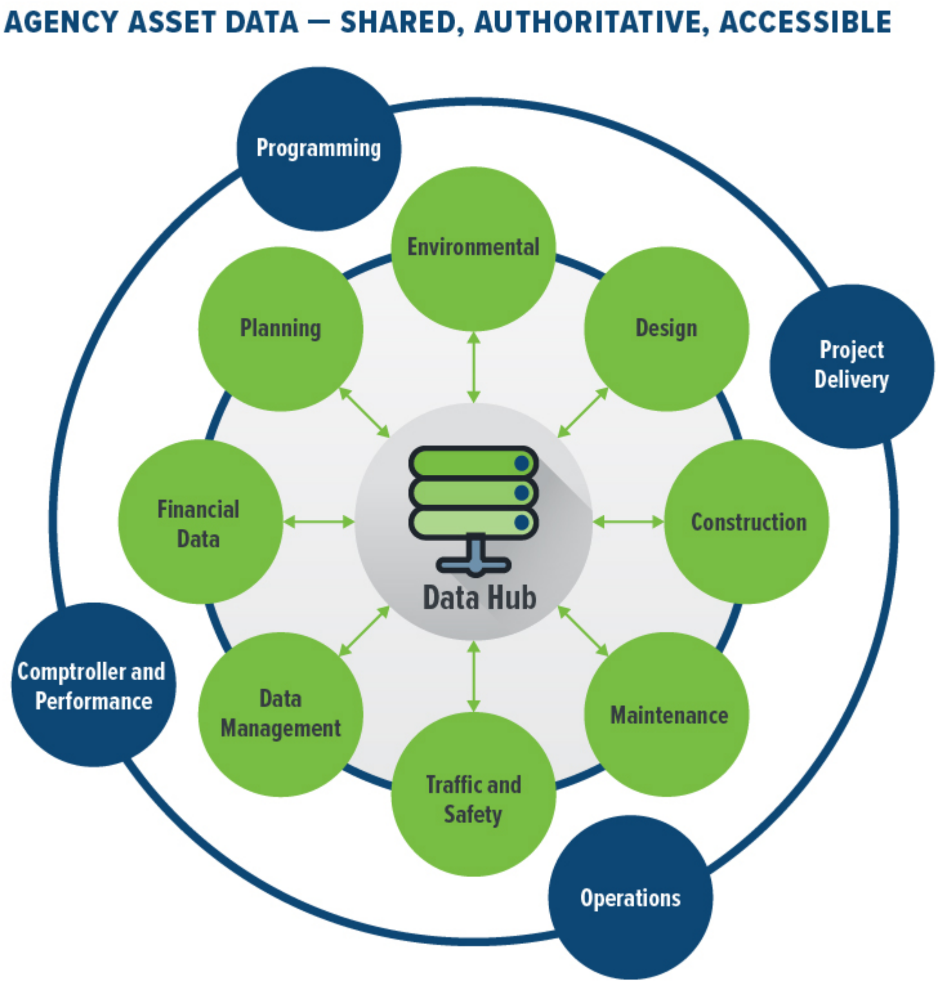


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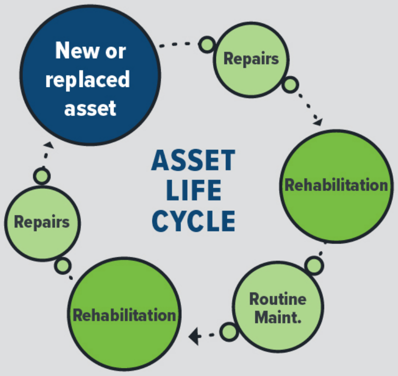
Figure 32. Graphic. BIM for infrastructure central data hub.

Managing the Full Asset Life Cycle—Cradle to Cradle

A central tenant of asset management is administration of an asset during its life cycle, at the lowest cost but providing the greatest benefit. Figure 33 illustrates how a typical agency might manage an asset during its entire life cycle.

Agencies plan, design, construct, and maintain assets in a continuous cycle, from cradle to cradle. For example, an asset may begin its "life" in planning, maintenance, or the design phases. Many assets may originate from an agency's capital program. The assets developed during the construction phase will then be maintained in the operational phases. Assets such as pavements and bridges may be maintained and renewed for decades. Other assets, such as signs, guardrails, and signals, may be modified as components reach their expected life or are systemically updated. Agencies are better able to manage the life of an asset when data is shared across the business units that are responsible for each life-cycle stage.



LIFE OF THE ASSET CRADLE TO CRADLE

Example: Guardrail/Attenuator

- Planning—roadway characteristics, funding
- Design/Construction—location, type, specification, costs
- Maintenance—up-to-date inventory, treatments and costs
- Safety—crash history, analysis results, and performance data
- Benefits—Agency manages the assets with all available information

Figure 33. Graphic. Data for cradle-to-cradle asset management.

Figure 33 presents an example of the types of data that are collected and used through the life cycle of guardrails and attenuators. The BIM for infrastructure concept can enhance the management of an asset during its life cycle by ensuring decision-makers in each phase have access to the data that was collected or used in previous phases. Figure 34 provides a summary of how Utah DOT is implementing cradle to cradle asset management through BIM for infrastructure.

UTAH DEPARTMENT OF TRANSPORTATION

ZERO FATALITIES, INJURIES, AND CRASHES

In 2012, Utah integrated department databases across many of the agency business systems. UDOT branded this integration of databases UPlan. During the same timeframe, UDOT completed a statewide asset inventory, the scope of which was the geospatial location of all above-ground assets and corresponding attributes. Taking advantage of these efforts, the Traffic and Safety Division created a "Safety App" that provides crash information and asset inventory that is authoritative and timely, all at the user's fingertips.

Since 2014, Traffic and Safety has had the ability to display all crashes (vehicle, bicyclist, and pedestrian), and existing asset inventory (signs, guardrail, etc.) on a map interface. This cloud- and map-based game-changing information technology allows the user to query for crashes by severity, specific crash attribute (run of the road, age of the driver), and specific assets (the presence of rumble strips, guardrail, width, curvature of the road, etc.).

This easy-to-use technology enhances the planning and project development practices by providing complete, timely, and accurate data to users throughout the agency.

Figure 34. Graphic. Summary of Utah DOT's management integration noteworthy practice.

IMPLEMENTING BIM FOR INFRASTRUCTURE

Implementing BIM for infrastructure requires an agency to determine where data/information resides, what business units are collecting, producing, or consuming information, how data is formatted, and how data is used. It also requires the establishment of a strong geospatial foundation that includes a single LRS calibrated to real world coordinates—latitude, longitude, and elevation. The aspects of BIM for infrastructure that are particularly relevant to developing and expanding asset management programs are discussed in the next sections. Additional information can be found in NCHRP Report 831, *Civil Integrated Management (CIM) for Departments of Transportation* (NCHRP 2016).

Figure 35. Graphic. General guidance for BIM implementation.

Figure 35 provides an overview of what an agency should consider when developing a plan for implementation. The agency will need to come to consensus on what is truly critical, not only to the success of individual business units but the agency, too. The agency's long-term goal should be integration of all data that is accessible through a single data portal to identify specific steps, budgets, and schedules for making IT improvements related to BIM for infrastructure.

Establishing an Implementation Roadmap

BIM for infrastructure requires a comprehensive review of an agency's IT systems that are used for asset management. Due to the costs and level of effort needed to change or modernize IT systems, agencies should expect the transition to BIM to take several years and involve multiple projects or internal efforts. Creation of a BIM roadmap can help ensure BIM for infrastructure implementation progresses over such a long timeframe. The roadmap should include a set of actions or projects the agency will undertake to improve data quality, governance, management, and sharing.

Data Hub Creation

Asset data refers to all agency data/information, including but not limited to financials, projects, programs, and physical assets. Typically, agency data reside in many different isolated business systems that were developed independently to manage daily operations for specific areas such as design, maintenance, and/or safety. The goal of BIM for infrastructure is for the agency to organize and share digital asset data in a central "hub." Every day, agencies produce and create more data and more information—"as-builts" (signs, guardrails, miles of pavement), crashes (location and attributes), the agency statewide transportation improvement plan (STIP), financial data, and projects past and present across the organization—that are managed and added to the hub. Figure 36 provides an example of how Florida DOT is integrating its data systems to improve decision-making.

FDOT FLORIDA DEPARTMENT OF TRANSPORTATION

ENTERPRISE INFORMATION MANAGEMENT

During the last several years, Florida Department of Transportation (FDOT) has been implementing a statewide initiative to organize and manage agency data. FDOT has launched this effort to meet the challenges of big data by integrating technology and business systems. FDOT's vision is to change the agency culture by transforming data into information.

This effort combines the resources, goals, and objectives of Florida's Technology and Operation Divisions into the initiative known as ROADS, which stands for:

- R—Reliable, accurate, authoritative, accessible data
- O—Organized data that produces actionable information
- A—Accurate governance-produced data
- D—Data and technology integration
- S—Shared agency data to perform cross-functional analysis.

Florida's goal is to create a foundation for success. In order to achieve this goal, the reorganized agency has created processes, procedures, and guidelines so that all data (financial, safety, project, program, assets, etc.) are organized and accessible.

Florida's steering committee, known as RET (ROADS Executive Team), is led by the agency's Chief of Transportation Technology and Civil Integrated Management Officer. The committee, which includes district secretaries, financial and planning executives, and operational directors, is charged with governance leadership and instituting processes that will change the culture of the agency by converting data to knowledge.

Four ROADS initiatives are in progress: Safety, Grants, Assets, and Data Warehouse. These 6-month implementation efforts are creating the framework, agency processes, governance structure, procedures, data dictionaries, and business system glossaries. The Safety initiative will manage crash data across the roadway system. The Grants initiative will include management, funding, programs and projects of MPOs, and city and county governments. The Asset initiative will standardize inventory attributes for 120 different classes of infrastructure assets and the agency's approximately 170 enterprise software applications. Part of this effort is to determine specific authoritative source data to include in the data warehouse. The fourth initiative is the development of the agency's data warehouse. The warehouse will provide a single authoritative site for sharing the accurate data. Five additional initiatives will kick off over the next 4 years.

Through the ROADS initiatives, Florida DOT has created a strategic direction for data integration covering data stewards, division responsibilities, asset inventory, business system integration, and an implementation roadmap. By coordinating its efforts, the agency is able to maximize the value of its data while streamlining processes for data collection, management, and dissemination.

Figure 36. Graphic. Florida DOT BIM implementation noteworthy practice example.

Figure 37 illustrates how a transportation agency might integrate asset data by creating a central data hub. For simplicity, just a few agency business databases are displayed—STIP/Design, Construction, Maintenance, and the Linear Reference System (LRS). The diagram illustrates how all business systems could be loaded into the central data hub—a location of authoritative agency data including asset data. Users would not access individual business systems but instead would access needed data through the authoritative data hub. Also, applications would have access through the authoritative data hub. Applications might include in-house developed, custom off the shelf (COTS), third-party on-premises, and third-party software as a service (SAAS). Users would access data or applications from either department servers or from "the cloud." The agency could provide limited access to public users while providing a secure interface for those with a valid user ID. Implementation of a data hub would require the agency to evaluate servers and storage requirements.

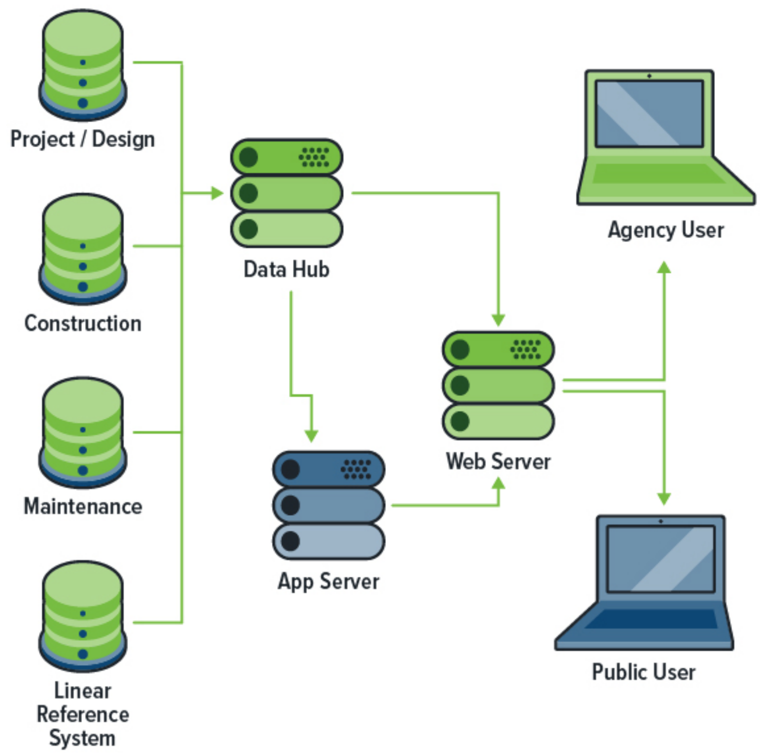


Figure 37. Graphic. Different elements of a high-level data integration network.

Managing the agency's data is a shared responsibility, making collaboration across business units critical for determining not only what data is needed to manage assets but also how the data will be organized and managed. Resources are not unlimited; therefore, it is important for the organization to set limits and determine what is critical to its mission. Business units should review how inventory and management of specific assets will help foster and improve the agency's mission. The agency's strategic direction, goals, and performance measures will help focus the individual business units on what is critical to the success of the organization. Several international standards exist to help agencies design and develop their data model. One commonly-followed standard is the International Organization for Standards (ISO) International Standard 16739:2013, *Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries* (ISO 2013). The IFC describes the data model for building and construction industry data. It is a platform-neutral and open file format specification. The data model was developed by buildingSMART (formerly the International Alliance for Interoperability, IAI) to facilitate interoperability in the architecture, engineering, and construction (AEC) industry and is a commonly used collaboration format in BIM-based projects. This standard can also be adapted for use in BIM for infrastructure.

Extract, Translate, and Load Data

Once the data hub is established, data is extracted, translated, and loaded from agency business systems into the data hub. A series of software scripts and routines would be used for the extraction, translation, and loading of data (see the following Data Requirements section). The routines would make business system database tables readable, intuitive, and understandable. The loading ensures data accuracy and integrity and follows agency governance policies. All data extracts would run after business hours each night to avoid impacting application performance during business hours.

The example shown in table 10 demonstrates how a small subset of data is pulled from four existing business applications: STIP/Design, Construction, Maintenance, and LRS. Table 10 identifies a few data elements that might be extracted from each application. In this example, data element names represent the data as it is known by the end-users or displayed on reports and may not reflect the name of the field where the data is stored.

Table 10. Example data elements used in a BIM implementation.

DATA ELEMENT	SYSTEM OF RECORD	SECURITY ACCESS	COMMENT
Project Manager	Design	Public	Include title, District
PM Phone Number	Design	Public	Include e-mail, District e-mail, address
Letting Date	Construction	Public	Add Note: "Subject to Change"
Contract Amount	Construction	Internal	May be shared with Public
Contract Change Orders	Construction	Internal	Include percentage of original contract amount that may be shared with Public
Sign Inventory	Maintenance	Public	Report by State Route and Milepost
Sign Attributes	Maintenance	Internal	Each Attribute is a separate, specific data element
Functional Classification	LRS	Public	Provide top 6 functional road classifications
Pavement Attributes	STIP	Public	Specific Data Elements—Sq. Yds., Section, Type, Distress, Next Sch. Treatment
State Route, Milepost	LRS	Public	Converts all street names to Route and Milepost
Pavement Management Sections, Distresses	Maintenance	Public	Reports all pavement information to a single authoritative "section"
Bridge Inventory	Maintenance	Internal	Location assigned to center of bridge deck

Data Governance

For data to be shared effectively within an agency or with external stakeholders, the data needs to be well defined. All groups responsible for collecting, managing, organizing, and using the data should manage to the same standards—also known as data governance. Figure 38 provides a noteworthy practice on how Ohio DOT has taken advantage of data governance tools to improve its TAM practices.

In a BIM for infrastructure environment, software scripts can translate information collected to different standards (time, description, LRS) into the central data hub, but this is not a trivial task. An agency will find the integration task easier if it establishes governance policies for the organization. The governance policies should address authoritative sources of information: geospatial, assets and asset attributes, division roles and responsibilities, reporting years (calendar, State, and Federal time periods), and program/project ownership. As an example, an agency asset data dictionary governance policy would assign the following to responsible parties:

- What assets are to be inventoried?
- What attributes will be collected?
- How will financial data be collected?
- How is information stored?
- How often is specific asset data to be updated?

OHIO DEPARTMENT OF TRANSPORTATION

Ohio DOT information is centrally organized in a data warehouse (Oracle) and publicly displayed through ODOT's web-mapping portal known as TIMS—Transportation Information Management System. Ohio brands its TIMS site with the phrase "Better Data Better Decisions." The TIMS system provides the user the ability to query, develop, and share maps of not only asset information but also many other data sets, such as projects, traffic, environmental, and safety information.

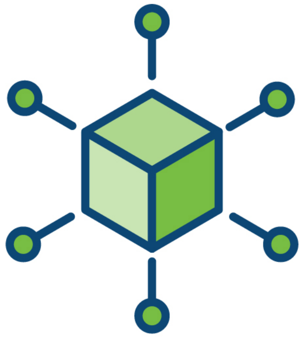
Information can be viewed from a desktop or a mobile device. Data can be exported to shapefiles, KMZ-KML, Excel, or geodatabases. Work is beginning on the development of Business Intelligence (BI) products, such as straight-line-diagrams and query tools. Future efforts also include linking financial and asset management databases.

Figure 38. Graphic. Ohio DOT BIM for infrastructure noteworthy practice.

THE FUTURE OF BUILDING INFORMATION MANAGEMENT

The goal is for agencies in the future to be able to have complete knowledge of all information pertaining to the entire asset inventory. The future of BIM for infrastructure may include:

- Business systems that track and share information.
- Asset information that is managed, organized, and shared across the entire highway agency.
- 3-D Design and Construction, described further in figure 39, using software that can produce 3-D digital and as-built plans.
- As-built plan files that are delivered in the agency's Data Dictionary format.
- Secure data using techniques such as authentication routines.
- Information that is provided from the cloud to agency by map-based apps.
- Big data and database architecture that improve data sharing and decision-making save agencies time and resources.



3D DESIGN MODELING AND CONSTRUCTION

Three-dimensional (3D) Design and Construction in transportation is a mature technology that serves as the building block for the modern-day digital jobsite. The technology allows for faster, more accurate and more efficient planning, design, and construction. As the benefits are more widely recognized, many in the U.S. highway industry will transition to 3D Design and Construction over the traditional two-dimensional (2D) design process.

Using 3D design and construction, teams can connect virtually to develop, test, and alter project designs throughout the design and construction phases. Intricate design features can be viewed geospatially, or in a 3D view, from multiple perspectives. Simulations can be run to detect design flaws before construction begins. Data exported from the 3D Design models can be transferred to a global positioning system (GPS) machine control that guides and directs construction equipment like bulldozers, excavators, and paving machines. The connectivity allows workers to receive and work with the most accurate, up-to-date models even if mid-cycle design changes are made.

A few agencies now require contractors to provide digital "As-Builts" in the departments data dictionary format (assets with specific attributes).

Figure 39. Graphic. 3D Design Modeling and Construction.

SUMMARY

BIM for infrastructure is an information management philosophy that provides a framework for integration of data from an agency's different business systems. It can form a reliable basis for managing assets during the entire life cycle, from conception to demolition, of the asset. Data integration can drive innovation in an agency, producing significant cost and time savings. Integration also helps ensure that limited funding is allocated based on engineering analysis and judgment as well as the best available information. Wise data-driven decision-making will stretch funding and resources and improve transparency in an agency.

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GLOSSARY OF TERMS

Ancillary Asset: All physical assets other than pavements and bridges, as defined by 23 U.S.C. 119, that a transportation agency wishes to or does manage.

Asset: A physical roadway infrastructure item that has value. Assets are sometimes referred to as roadway "furniture" or "features." An asset may be a single item, such as a sign, or a linear item, such as a road or guardrail section. An asset may also be a spatial item such as a rest area or mowable acreage.

Asset Class: Assets with the same characteristics and function (e.g., bridges, culverts, tunnels, pavements, or guardrail) that serve a common function (e.g., roadway system, safety, Intelligent Transportation, signs, or lighting).

Asset Inventory: A complete list of assets, including location, attribute, and condition data needed for management of the assets throughout their life cycles.

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

Asset Prioritization: A methodology for ranking asset classes into prioritized tiers.

Asset Subgroup: A specialized group of assets within an asset class with the same characteristics and function (e.g., concrete pavements or asphalt pavements).

Building Information Management (BIM) for infrastructure: A system of processes for digital data and the collaborative exchange of that data during all stages of the asset management life cycle.

Business Unit: A generic term for an organizational unit within a transportation agency at any level of the agency's hierarchy (e.g., department, office, division, bureau, or unit).

Civil Integrated Management (CIM): The technology-enabled collection, organization, managed accessibility, and use of accurate data and information throughout the life cycle of a transportation asset.

Condition Assessment: A physical inspection and rating of roadway assets to determine the condition of individual assets, roadway sections, or overall road networks.

Condition-Based Maintenance: A maintenance approach in which maintenance activities are scheduled based on regularly monitored performance.

Data Collection: The act of recording measurements or observations as discrete data elements in a software product.

Data Dictionary: A document or data set that describes the attributes of data elements to be collected (e.g., the appropriate level of detail, the data owner, and the level of accuracy that is expected of each asset).

Data Governance: The discipline that establishes the criteria and requirements for data; their quality, management, policies, and business process; and risk management for handling of data. In short, it is a corporate approach to collecting and managing data.

Data Needs: Essential and desirable data (asset inventory, condition, maintenance, and other attributes) that are needed to support reliability-based decision-making.

Failure Modes and Effects Analysis (FMEA): An analysis approach used in RCM in which each system, subsystem, and component is evaluated to determine the loss of function that would constitute a failure.

Flash LiDAR: A specific type of LiDAR that illuminates the whole area of interest at once with laser light as opposed to scanning the area of interest with one or more laser beams.

Interval-Based Maintenance: A maintenance approach in which maintenance activities are scheduled at specific time intervals based on analysis of asset performance.

LiDAR: An acronym for light distancing and ranging. It is a surveying technique that operates on the same principle as radar but uses pulses of light to detect distances from the sensor to objects. Pulses of light in the form of lasers are emitted. They travel to objects and reflect back to the sensor.

Maintenance Management: The actions associated with organizing, administering, and supervising highway maintenance activities, customer services, and infrastructure preservation.

Maintenance Management System (MMS): A framework of policies, procedures, and standards, supported by software, used to manage and support the activities involved with maintaining highway assets.

Nondestructive Evaluation (NDE): Any of a set of methods for collecting information on an asset without causing damage to the asset.

Performance-Based Management: A strategic approach of using data to set goals and assess progress toward achieving those goals.

Performance Measure: A unit of measurement for rating asset condition or maintenance performance.

Performance Target: A level of performance defined using a specific performance measure that is established as an objective to be achieved within a specific period.

Photogrammetry: A survey technique that uses photography to determine the location of objects.

Priority Tiers: Groups of assets that will be added to an asset management program with a common effort or within the same timeframe.

Reactive Maintenance: A maintenance approach in which maintenance activities are performed in response to reported asset conditions or events.

Reliability-Centered Maintenance (RCM): The process used to determine the most effective maintenance strategy to ensure that a physical asset continues to perform in a manner consistent with design specifications. The primary objectives of RCM are to maximize asset reliability and minimize life-cycle costs by integrating maintenance approaches rather than applying them independently. The three main components of an RCM program that are most relevant to ancillary highway assets are condition-based maintenance, interval-based maintenance, and reactive maintenance.

Risks: The potential consequences, positive or negative, arising from uncertainty.

Transportation Asset Management Plan (TAMP): A document that describes how a highway agency will carry out asset management. This includes how the agency will make risk-based decisions from a long-term assessment of the transportation system as it relates to managing its physical assets and laying out a set of investment strategies to address the condition and system performance gaps. This document describes how the highway network system will be managed to achieve targets for asset condition and system performance effectiveness while managing the risks, in a financially responsible manner, at a minimum practicable cost over the life cycle of its assets.

ACRONYMS

ADA	Americans with Disabilities Act
AASHTO	Association of State Highway and Transportation Officials
BIM	Building Information Management
CIM	Civil Integrated Management
COTS	Custom off the Shelf
DOT	Department of Transportation
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMEA	Failure Modes and Effects Analysis
GPS	Global Positioning System
ISO	International Organization for Standards
IT	Information Technology
LiDAR	Light Image Detection and Ranging
LRS	Linear Referencing System
MMS	Maintenance Management System
MQA	Maintenance Quality Assurance
NCHRP	National Cooperative Highway Research Program
NDE	Nondestructive Evaluation
NHI	National Highway Institute
RCM	Reliability-Centered Maintenance
SAAS	Software as a Service
STIP	Statewide Transportation Improvement Plan
TAM	Transportation Asset Management
TAMP	Transportation Asset Management Plan